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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-23)

C. A. Rafferty

ARO, Inc.

June 1968

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LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (I-E-J), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2 rocket engine, and McDonnell Douglas Corporation, Douglas Aircraft Company, Missile and Space Systems Division, manufacturer of the S-IVB stage. The testing reported herein was conducted on January 10, 1968, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on April 12, 1968.

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This technical report has been reviewed and is approved.

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ABSTRACT

Five firings of the Rocketdyne J-2 rocket engine (S/N J-2047) were conducted in Test Cell J-4 of the Large Rocket Facility on January 10, 1968. The firings were accomplished during test period J4-1801-23 at pressure altitudes ranging from 105,500 to 113,000 ft at engine start to evaluate the effects of predicted Saturn S-II stage pre-fire conditions on J-2 engine start transients. Engine components were thermally conditioned to simulate the expected S-II interstage/engine thermal environment. Satisfactory engine operation was obtained. Accumulated firing duration was 56.3 sec.

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NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start, designated as the time that helium control and ignition phase solenoids are energized
GG	Gas generator
MOV	Main oxidizer valve
NPSH	Net positive suction head, ft
STDV	Start tank discharge valve
t_0	Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, defined as engine vibration in excess of 150 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The five firings reported herein were conducted during test period J4-1801-23 on January 10, 1968, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to evaluate the effects of predicted S-II stage prefire conditions on J-2 engine start transients. These firings were accomplished at pressure altitudes ranging from 105, 500 to 113, 000 ft (geometric pressure altitude, Z, Ref. 1) at engine start and with predicted S-II interstage/engine thermal environment as targets for conditioning engine components.

Data collected to accomplish the test objectives are presented herein. Copies of all data obtained during this test have been previously supplied to the sponsor, and copies are on file at AEDC. The results of the previous test period are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 230, 000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. An S-IVB battleship stage, with flight-type S-IVB stage pressure propellant supply ducts, was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 38,215 ft (1248 psia) of liquid hydrogen at a flow rate of 8585 gpm for a rotor speed of 27,265 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2170 ft (1107 psia) of liquid oxygen at a flow rate of 2965 gpm for a rotor speed of 8688 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel

turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46, 000 lb of liquid hydrogen and 199, 000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during S-II flight were routed to the respective facility venting systems.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100, 000 ft. The basic cell construction provides a 1.5-million-lb_f-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, main oxidizer valve closing control line and second-stage actuator, and start tank discharge valve opening control line. Helium was routed internally through the crossover duct and tubular-walled thrust chamber and externally over the main oxidizer valve closing control line and second-stage actuator and the start tank discharge valve opening control line.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III
PROCEDURE

Pre-operational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber, the crossover duct, start tank discharge valve closing control line, main oxidizer valve closing control line, and main oxidizer valve second-stage actuator. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Five firings of the J-2 rocket engine were conducted on January 10, 1968, during test period J4-1801-23. These firings were conducted to investigate J-2 engine S-II start transient characteristics with particular attention to the effects of thrust chamber and start tank conditions. Testing was accomplished at pressure altitudes ranging from 105,500 to 113,000 ft at engine start and with predicted S-II temperature and pressure start targets. Each firing was conducted following a 1-sec fuel lead.

Table VI presents the conditioning targets for engine components and the measured test conditions at engine start. Start and shutdown times of selected engine valves are presented in Table VII. Figure 8 shows engine start conditions for pump inlets, start tank, and helium tank. Specific test objectives and a brief summary of results obtained for each firing are presented as follows:

Firing	Test Objectives	Results
23A	Determine the effects of minimum start energy, coldest expected thrust chamber, and minimum main oxidizer valve second-stage ramp time on S-II engine chamber pressure buildup time and high level fuel pump stall margin.	Engine thrust chamber reached 550 psia at t_0 + 2.150 sec. Minimum fuel pump high level stall margin was 500 gpm. A conservative low level stall margin was experienced.
23B	Determine the effects of minimum start energy, warmest expected thrust chamber, and minimum main oxidizer valve second-stage ramp time on S-II engine chamber pressure buildup time and high level fuel pump stall margin.	Engine thrust chamber reached 550 psia at t_0 + 2.075 sec. Minimum fuel pump high level stall margin was 750 gpm. A conservative low level stall margin was experienced.
23C	Determine the effects of low start tank energy, coldest expected thrust chamber, and minimum main oxidizer valve second-stage ramp time on S-II engine chamber pressure buildup time and high level fuel pump stall margin.	Engine thrust chamber reached 550 psia at t_0 + 2.150 sec. Minimum fuel pump high level stall margin was 500 gpm. A conservative low level stall margin was experienced.

Firing	Test Objectives	Results
23D	Determine the effects of low start tank energy, maximum fuel pump inlet pressure, and warmest expected thrust chamber conditions on S-II engine chamber pressure buildup time and the augmented spark igniter ignition detect time.	Engine thrust chamber reached 550 psia at t_0 + 2.025 sec. Augmented spark ignition was detected 244 msec after engine start. Post-test inspection revealed no augmented spark igniter erosion had occurred during this test period.
23E	Determine the effects of coldest expected thrust chamber and low propellant net positive suction head (NPSH) on fuel pump low level stall for an S-II engine start.	A conservative stall margin was maintained throughout the low level region for this firing.

The presentation of the test results in the following sections will consist of a discussion of each engine firing with pertinent comparisons. The data presented will be those recorded on the digital data acquisition system, except as noted.

4.2 TEST RESULTS

4.2.1 Firing J4-1801-23A

The programmed 32.6-sec firing was successfully accomplished after a 1.0-sec fuel lead. Test conditions at engine start are presented in Table VI. Engine start and shutdown transients are presented in Fig. 9. Table VII presents selected engine valve operating times for engine start and shutdown transients. Engine ambient pressure and combustion chamber pressure during the test are presented in Fig. 10. Pressure altitude at engine start was 105,500 ft with a maximum of 99,000 ft during main-stage operation. Thermal conditioning of various engine components before firing 23A is presented in Fig. 11.

Start tank conditions for this firing at engine start included a temperature of -201°F and pressure of 1200 psia. Thrust chamber throat temperature, conditioned for the coldest expected S-II engine start, was -274°F. The main oxidizer valve second-stage ramp, conditioned for minimum ramp time, was timed at 1.770 sec during final dry sequence test and required 1.852 sec during the firing. Thrust chamber pressure attained 550 psia at t_0 + 2.150 sec.

Gas generator temperature reached an initial peak of 1614°F with no significant second peak, as shown in Fig. 9. Gas generator shutdown transients are presented in Fig. 9.

Fuel pump head/flow data are presented in Fig. 12 and show a minimum high level stall margin of 500 gpm at an approximate pump speed of 18, 000 rpm and a conservative low level stall margin. Main chamber pressure indicates the propellant utilization valve excursion occurred at approximately t_0 + 14 sec, changing the engine oxidizer-to-fuel mixture ratio from 5. 0 to 5. 5. Engine vibration safety cutoff counts (VSC) occurred for 26 msec beginning at t_0 + 1. 047 sec.

Engine steady-state performance data are presented in Table VIII. The data presented were for a 1-sec data average from 29 to 30 sec and were computed using the Rocketdyne PAST 640, modification zero performance computer program. Engine test measurement required by the program and the program computations are presented in Appendix IV. Normalized engine thrust was 236, 280 lb_f, which is 2. 73 percent higher than the rated thrust of 230, 000 lb_f.

4.2.2 Firing J4-1801-23B

The programmed 7. 6-sec firing was successfully accomplished after a 1. 0-sec fuel lead. Test conditions at engine start are presented in Table VI. Engine start and shutdown transients are presented in Fig. 13. Table VII presents selected engine valve operating times for engine start and shutdown transients. Engine ambient pressure and combustion chamber pressure during the test are presented in Fig. 14. Pressure altitude at engine start was 112, 500 ft with a maximum of 104, 500 ft during main-stage operation. Thermal conditioning of various engine components before firing 23B is presented in Fig. 15.

Fuel pump head/flow data are presented in Fig. 16 and show a minimum high level stall margin of 750 gpm at an approximate pump speed of 19, 500 rpm and a conservative low level stall margin. Engine vibration (VSC) occurred for 9 msec beginning at t_0 + 1. 032 sec.

Start tank conditions at engine start of -201°F and 1197 psia were essentially the same as firing 23A. Thrust chamber throat temperature, conditioned for the warmest expected S-II engine start, was -157°F. The main oxidizer valve second-stage ramp time was 1.953 sec. Engine thrust chamber pressure buildup time from t_0 to P_c = 550 psia was 2. 075 sec as compared to 2. 150 sec for firing 23A.

The 119°F warmer average thrust chamber at engine start on firing 23B produced greater fuel flow resistance than on firing 23A, thus causing higher fuel pump discharge pressure and greater gas generator fuel injection pressure (Fig. 13). This resulted in lower gas generator oxidizer-to-fuel ratio and thus lower gas generator initial temperature peak. Higher gas generator chamber pressure resulting from increased flow drove the turbopumps faster, delivering more oxidizer and fuel to the thrust chamber. This caused the 75-msec faster engine thrust chamber pressure buildup time. Gas generator shutdown transients are presented in Fig. 13. The increased hydraulic torque on firing 23B resulting from higher pump flow, as indicated by the differential pressure across the main oxidizer valve (Fig. 17), slowed movement of the main oxidizer valve second-stage ramp by 101 msec.

4.2.3 Firing J4-1801-23C

The programmed 7.6-sec firing was successfully accomplished after a 1.0-sec fuel lead. Test conditions at engine start are presented in Table VI. Engine start and shutdown transients are presented in Fig. 18. Table VII presents selected engine valve operating times for engine start and shutdown transients. Engine ambient pressure and combustion chamber pressure during the test are presented in Fig. 19. Pressure altitude at engine start was 113,000 ft with a maximum of 103,500 ft during main-stage operation. Thermal conditioning of various engine components before firing 23C is presented in Fig. 20.

Fuel pump head/flow data are presented in Fig. 21 and show a minimum high level stall margin of 500 gpm at an approximate pump speed of 19,000 rpm and a conservative low level stall margin. Engine vibrations (VSC) occurred for 47 msec beginning at t_0 + 1.055 sec.

Start tank conditions at engine start included a temperature of -141°F and a pressure of 1243 psia. Thrust chamber throat temperature at this same time was -292°F. The main oxidizer valve second-stage ramp time was 1.806 sec. Engine thrust chamber pressure buildup, from t_0 to P_c = 550 psia, required 2.150 sec, the same as firing 23A.

The gas generator initial temperature peak of 1412°F was 202°F lower than on firing 23A (Fig. 18). Gas generator shutdown transients are presented in Fig. 18. No significant difference between firings 23A and 23C was observed in either gas generator chamber pressure or thrust chamber pressure throughout the start transient. The higher start tank pressure on firing 23C tends to spin both turbopumps faster than on firing 23A. The lower temperature difference between start tank and crossover duct on firing 23C allows less additional energy input to the oxidizer pump driving gas and tends to produce a lower oxidizer pump speed, thus reducing the oxidizer pump discharge pressure and resultant flow to the gas generator. These conditions resulted in a lower gas generator initial temperature peak on firing 23C.

4.2.4 Firing J4-1801-23D

The programmed 7.6-sec firing was successfully accomplished after a 1.0-sec fuel lead. Test conditions at engine start are presented in Table VI. Engine start and shutdown transients are presented in Fig. 22. Table VII presents selected engine valve operating times for engine start and shutdown transients. Engine ambient pressure and combustion chamber pressure during the test are presented in Fig. 23. Pressure altitude at engine start was 111,500 ft with a maximum of 103,000 ft during main-stage operation. Thermal conditioning of various engine components before firing 23D is presented in Fig. 24.

Fuel pump head/flow data are presented in Fig. 25 and show a minimum high level stall margin of 800 gpm at an approximate pump speed of 19,500 rpm and a conservative low level stall margin. Engine vibration (VSC) occurred for 24 msec beginning at t_0 + 1.035 sec.

Start tank conditions at engine start included a temperature of -139°F and a pressure of 1249 psia. Thrust chamber throat temperature at engine start was -151°F. The main oxidizer second-stage ramp time was 1.940 sec. Engine thrust chamber pressure buildup time from t_0 to 550 psia required 2.025 sec.

Fuel pump inlet pressure at engine start was 41.1 psia, which was 14.7 psia greater than that experienced on firing 23C, also thrust chamber throat temperature was 141°F warmer than on firing 23C. All other start conditions for these two firings were essentially the same. Gas generator initial temperature peak of 1162°F is 250°F below the initial peak on firing 23C (Fig. 22). Gas generator shutdown transients are presented in Fig. 22. The higher fuel pump inlet pressure on firing 23D increased gas generator fuel injection pressure. This, coupled with the increased fuel flow resistance caused by a warmer thrust chamber, increased fuel flow to the gas generator, which decreased the initial temperature peak. After gas generator ignition, the chamber pressure (Fig. 22) was 50 to 60 psi higher than on firing 23C until main-stage operation. Increased oxidizer and fuel pump speeds, which are attributable to greater gas generator chamber pressure, resulted in a 125-msec faster engine thrust chamber pressure buildup on firing 23D.

Higher oxidizer pump speed and increased flow rate resulted in an increased hydraulic torque, as indicated by differential pressure across the main oxidizer valve (Fig. 26). This delayed the main oxidizer valve second-stage ramping time on firing 23D by 134 msec as compared to firing 23C.

4.2.5 Firing J4-1801-23E

The programmed 0.95-sec firing was successfully accomplished after a 1.0-sec fuel lead. Test conditions at engine start are presented in Table VI. Engine start and shutdown transients are presented in Fig. 27. Table VII presents selected engine valve operating times for engine start and shutdown transients. Engine ambient pressure and combustion chamber pressure during the test are presented in Fig. 28. Pressure altitude at engine start was 110,500 ft. Thermal conditioning of various engine components before firing 23E is presented in Fig. 29.

Fuel pump head/flow data are presented in Fig. 30 and show a conservative low level stall margin was maintained throughout the firing. No engine vibration (VSC) was recorded for this firing.

Start tank conditions at engine start included a temperature of -241°F and a pressure of 1394 psia. Crossover duct average temperature at engine start was 38.3°F. Thrust chamber throat temperature was -267°F. Propellant pump inlet pressures at engine start were both below minimum model specifications, as per test requirements. Fuel pump inlet pressure and oxidizer pump inlet pressure were 24.7 and 28.2 psia, respectively.

The gas generator initial temperature peak of 1688°F (Fig. 27) occurred after engine cutoff, whereas a value of 1647°F was experienced at cutoff, t_0 + 0.950 sec. Oxidizer pump speed reached a peak of 3590 rpm. The fuel pump attained a speed of 13,688 rpm at engine cutoff, with the peak speed of 13,766 rpm occurring at t_0 + 1.075 sec.

Net positive suction head for the fuel pump on firing 23E is shown in Fig. 31. A minimum NPSH value of 100 ft occurred at 0.3 sec during the engine start transient. From 0.25 to 0.50 sec of the start transient, fuel pump NPSH is less than minimum model specification NPSH. Pump performance and engine start transients indicate satisfactory pump operation throughout this firing.

4.3 POST-TEST INSPECTION

Post-test leak checks of the J-2 engine revealed a fuel turbine seal leak in excess of 10,000 scim. This seal was replaced before the following test period.

SECTION V
SUMMARY OF RESULTS

The results of the five firings of the Rocketdyne J-2 rocket engine conducted on January 10, 1968, in Test Cell J-4 are summarized as follows:

1. An increase in thrust chamber temperature from -275 to -150°F resulted in faster thrust chamber pressure buildup and greater fuel pump high level stall margin.
2. An increase in start tank gas energy from 2640 Btu (1200 psia, -200°F) to 2710 Btu (1250 psia, -140°F) resulted in a longer thrust chamber pressure buildup time and an increase in fuel pump high level stall margin.
3. Fuel pump operation at low NPSH conditions (firing 23E) was satisfactory.
4. High and low level stall margins were conservative on all firings.

REFERENCES

1. Dubin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.
2. Collier, M. R. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-21 through J4-1801-22)." AEDC-TR-68-81 (to be published).
3. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1, August 1965.
4. Test Facilities Handbook (6th Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, November 1966.

APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

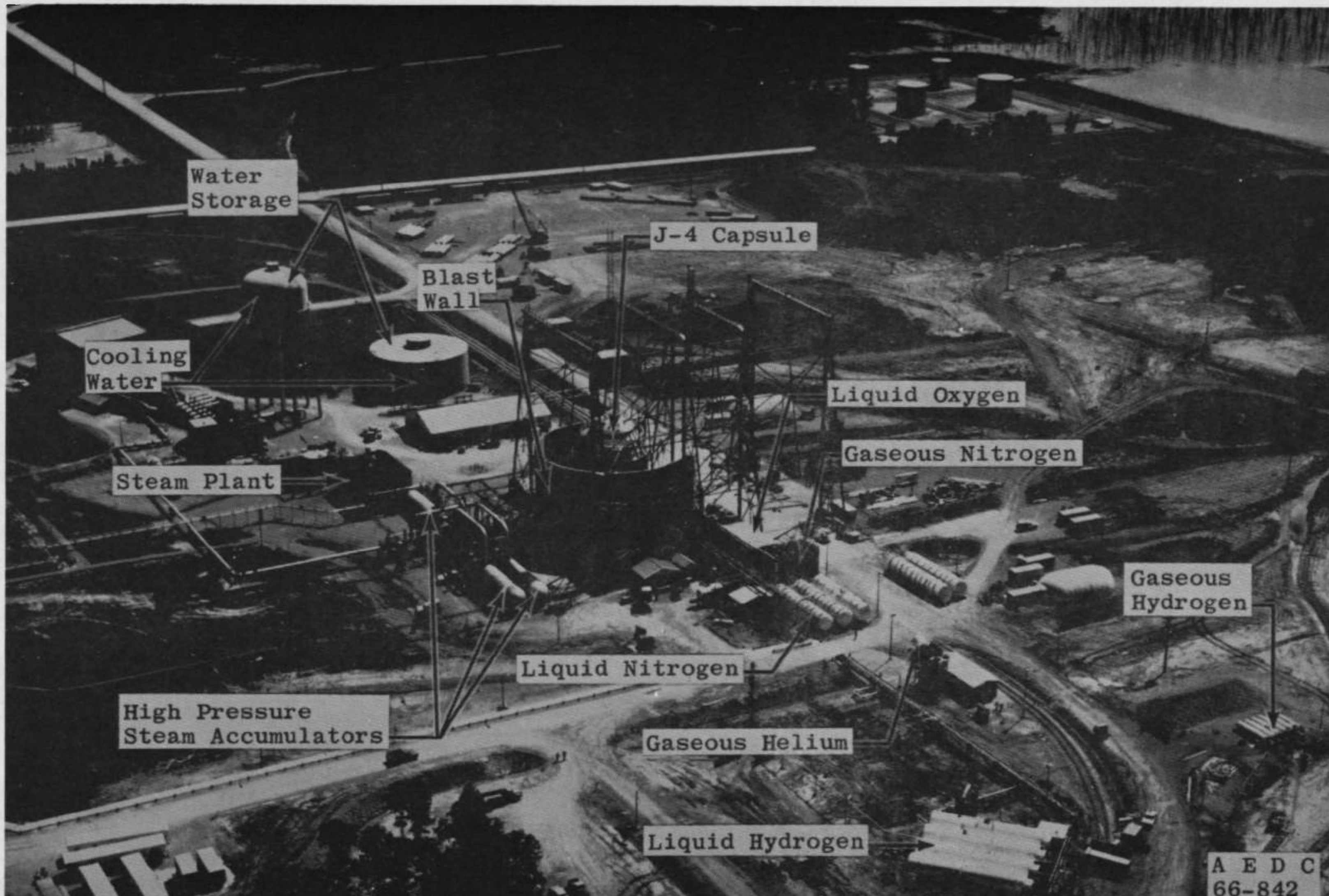


Fig. 1 Test Cell J-4 Complex

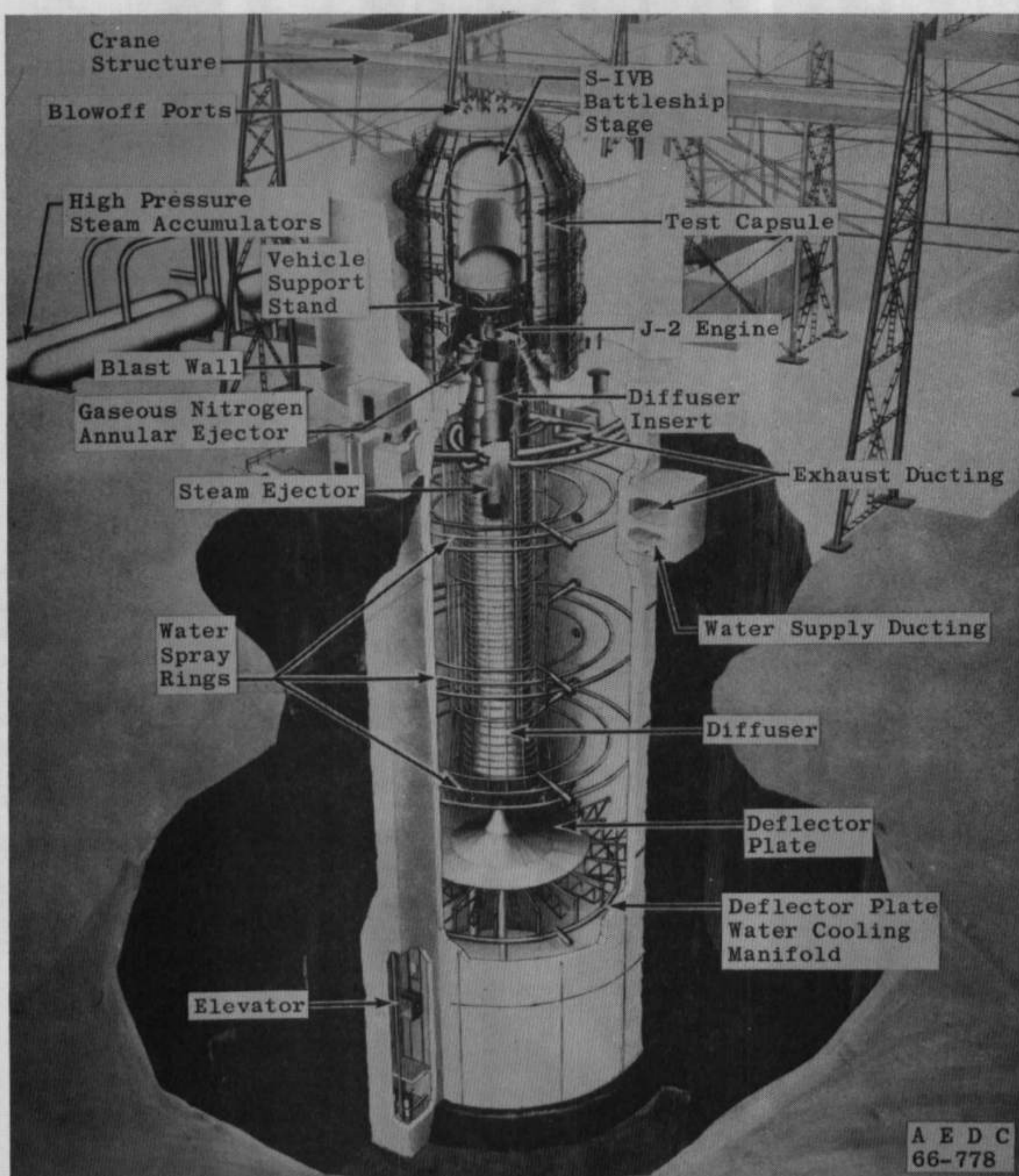


Fig. 2 Test Cell J-4, Artist's Conception

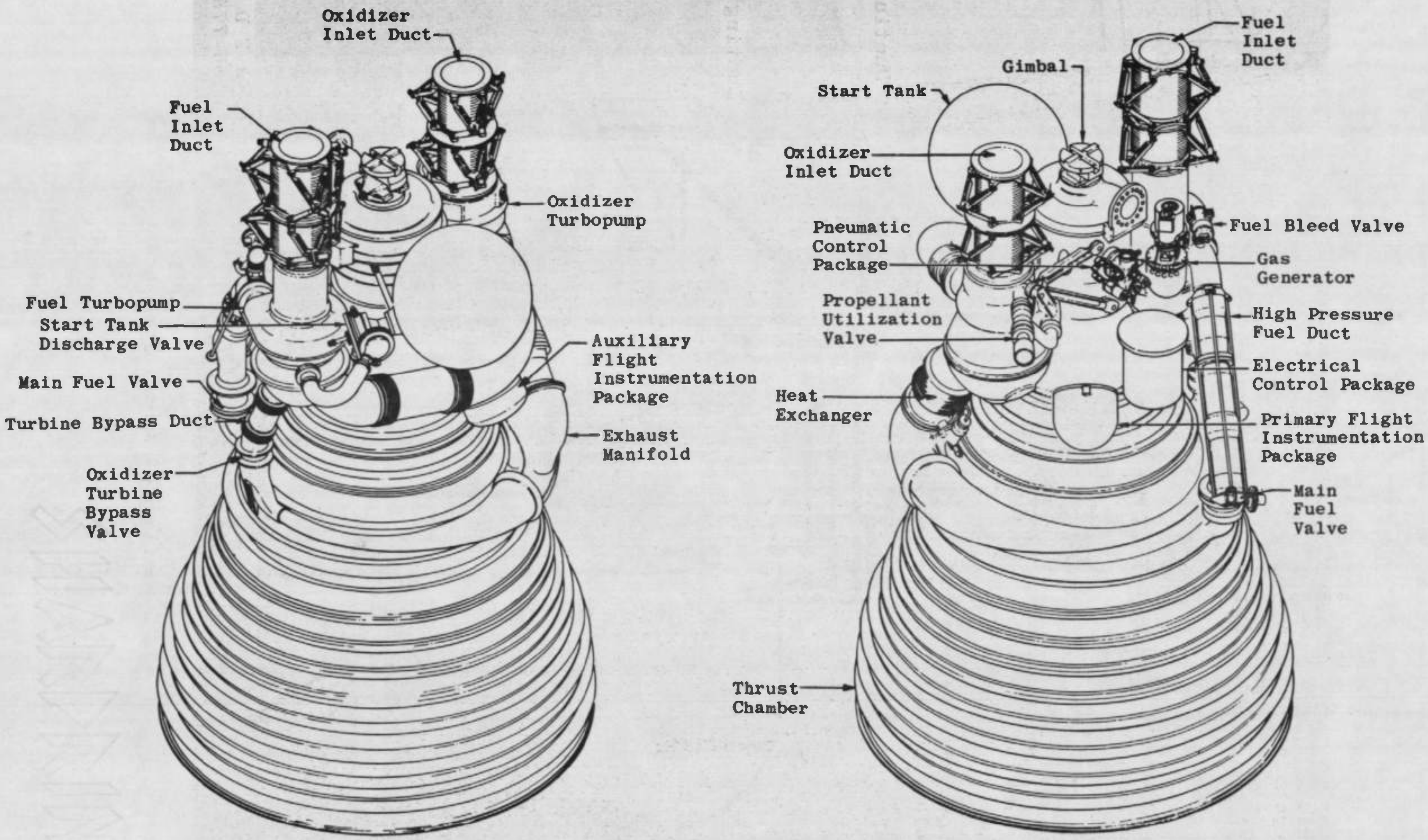


Fig. 3 Engine Details

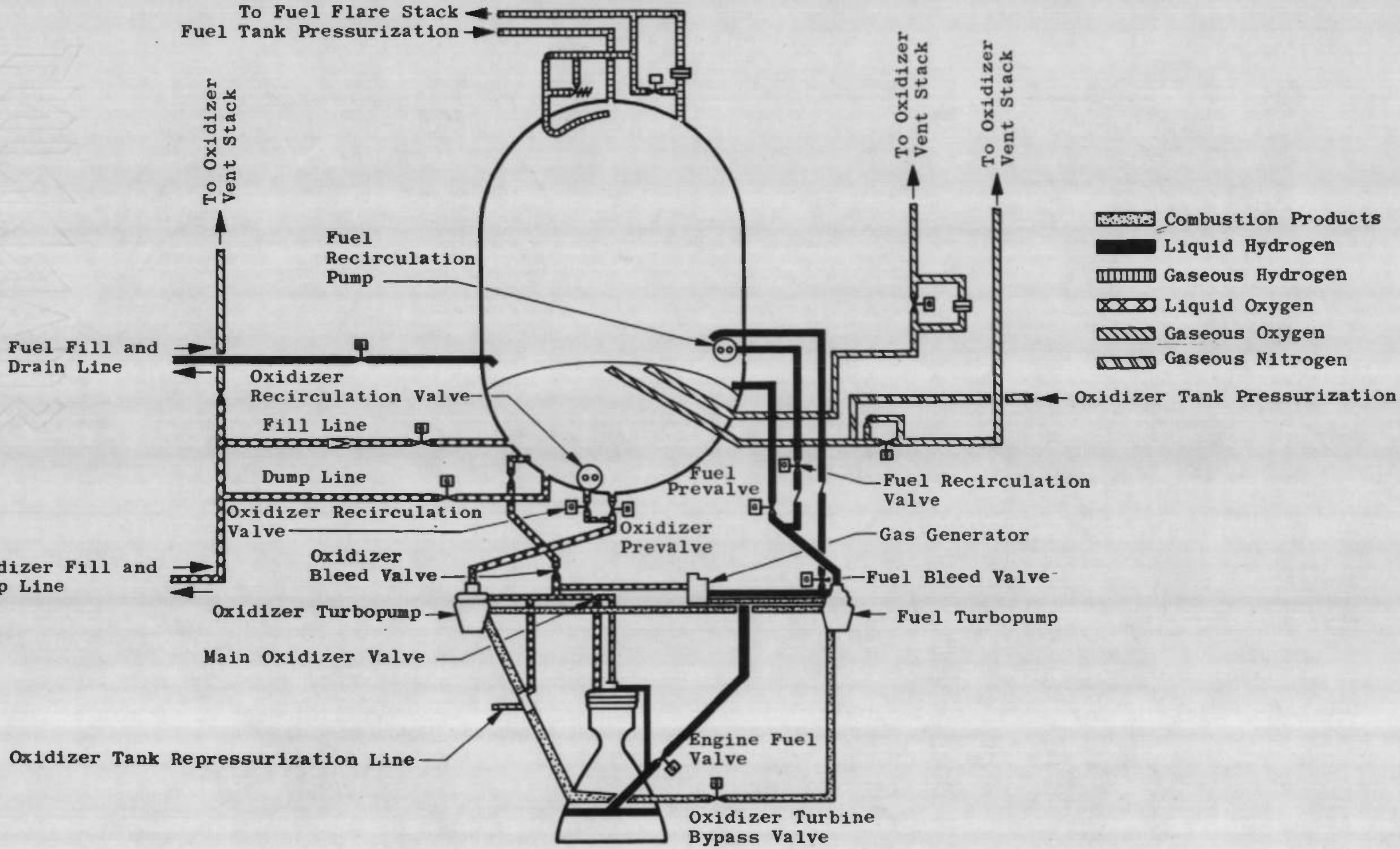


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

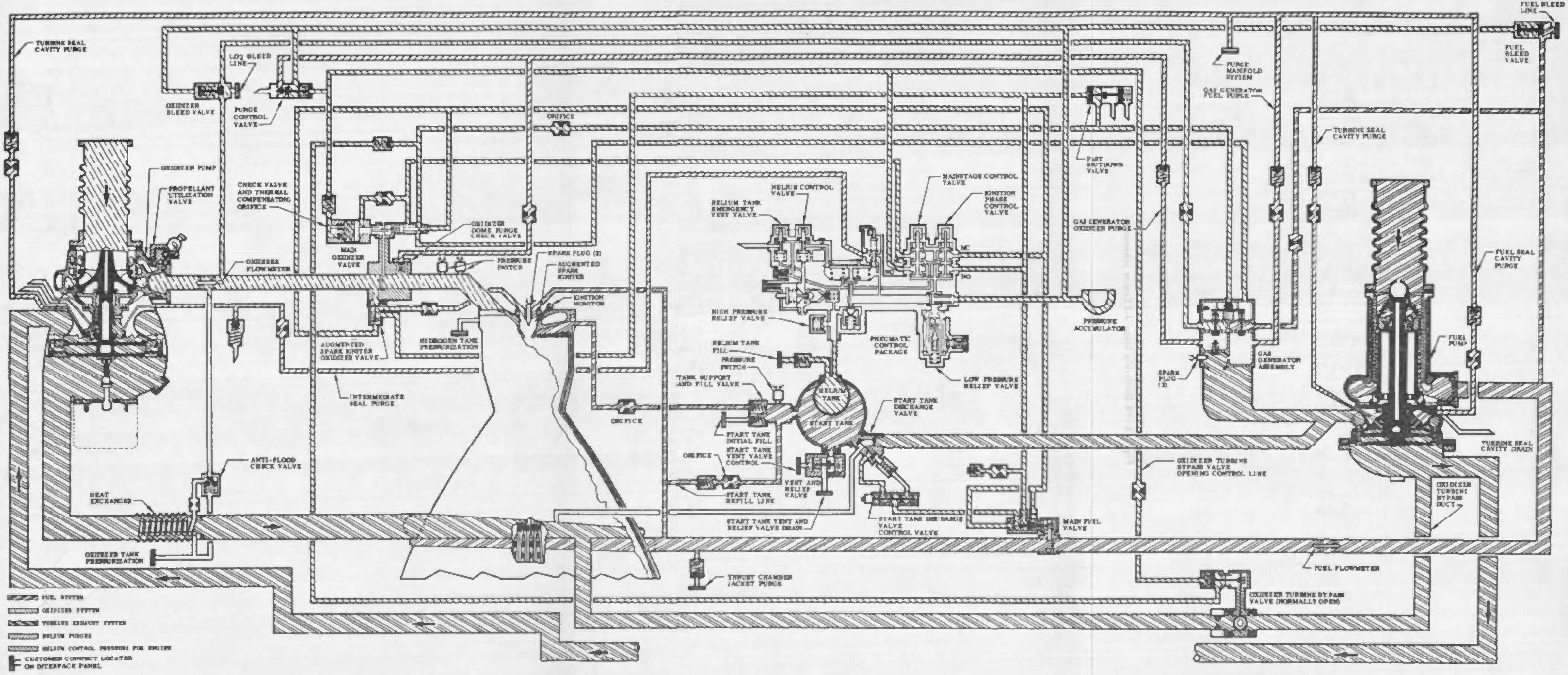


Fig. 5 Engine Schematic

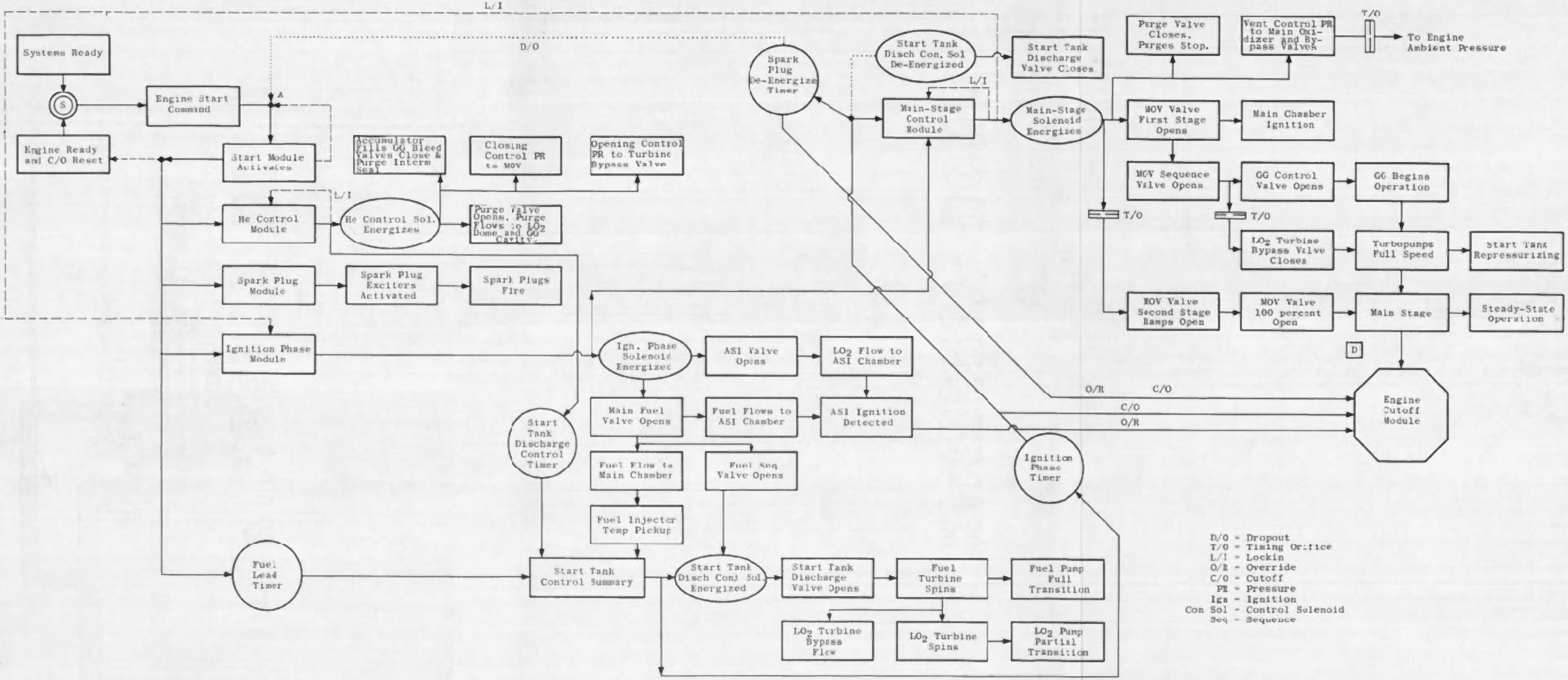
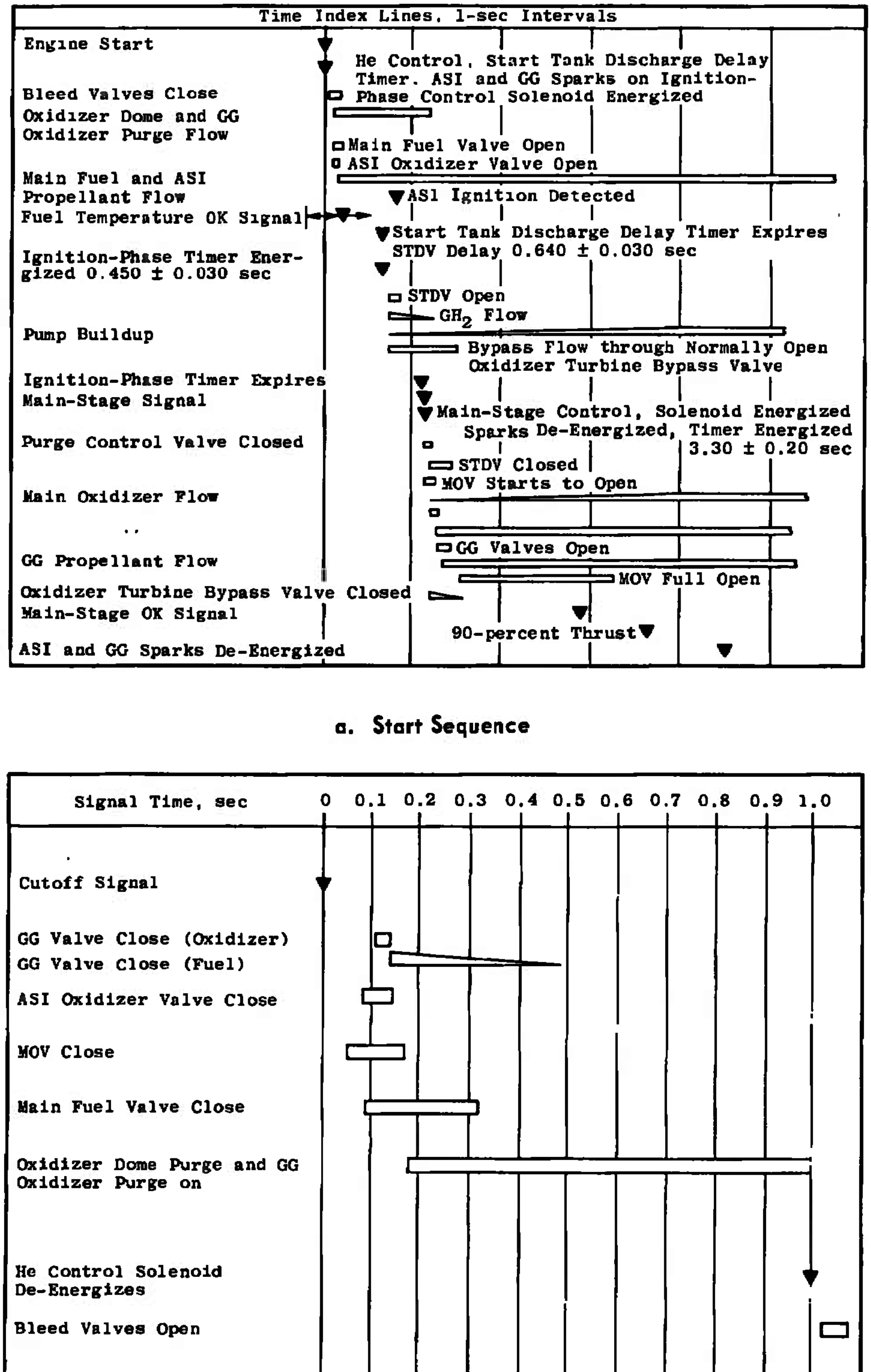


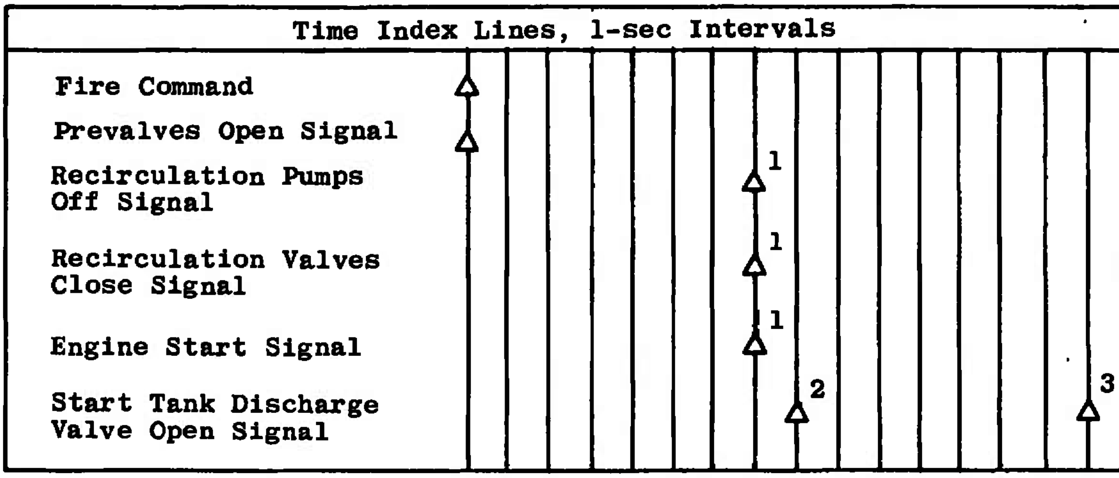
Fig. 6 Engine Start Logic Schematic



a. Start Sequence

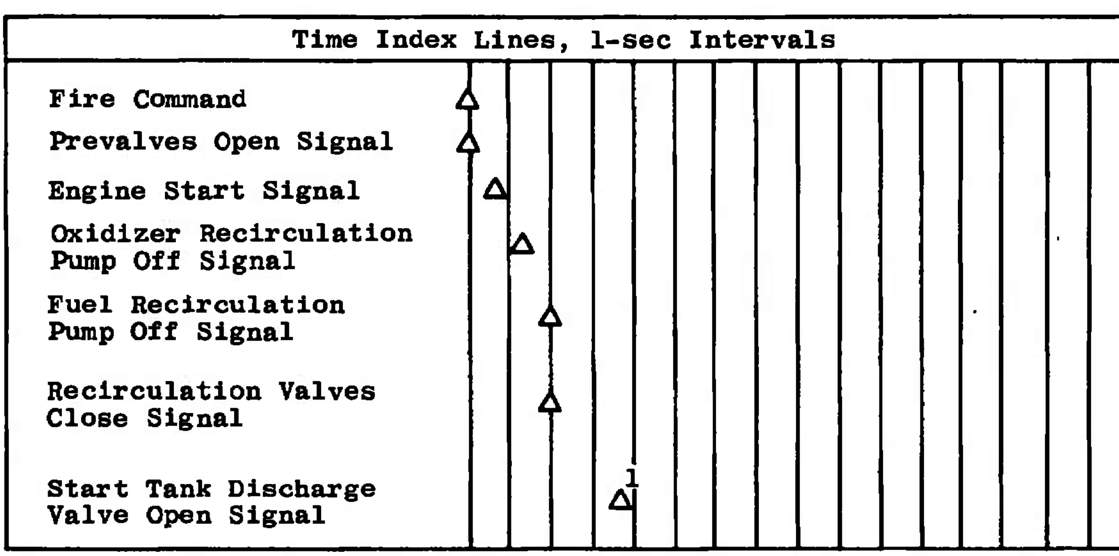
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



[1]Nominal Occurrence Time (Function of Prevalves Opening Time)
[2]One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3]Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

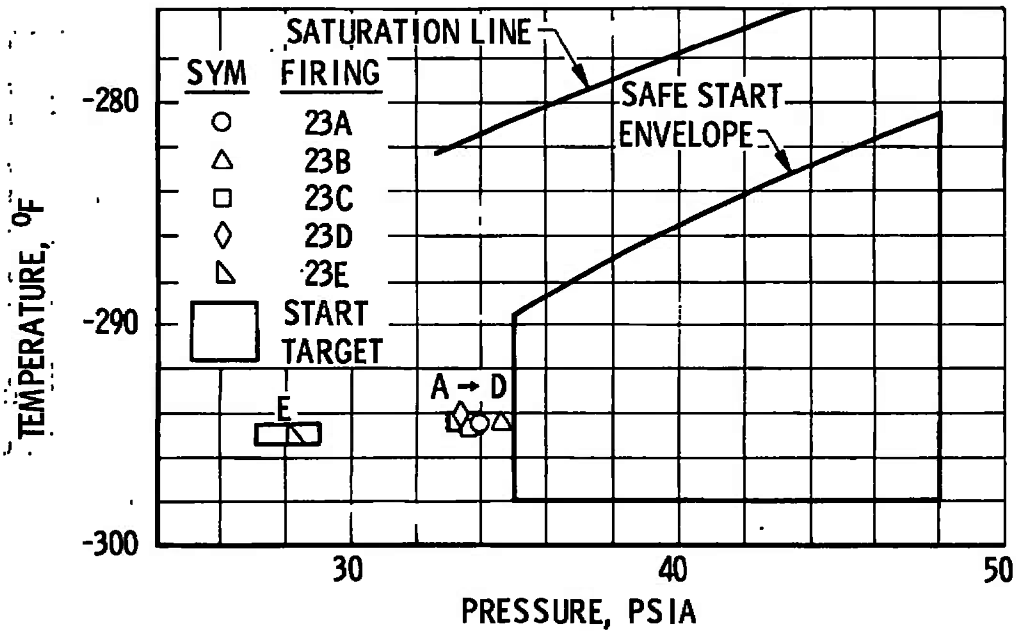
c. Normal Logic Start Sequence



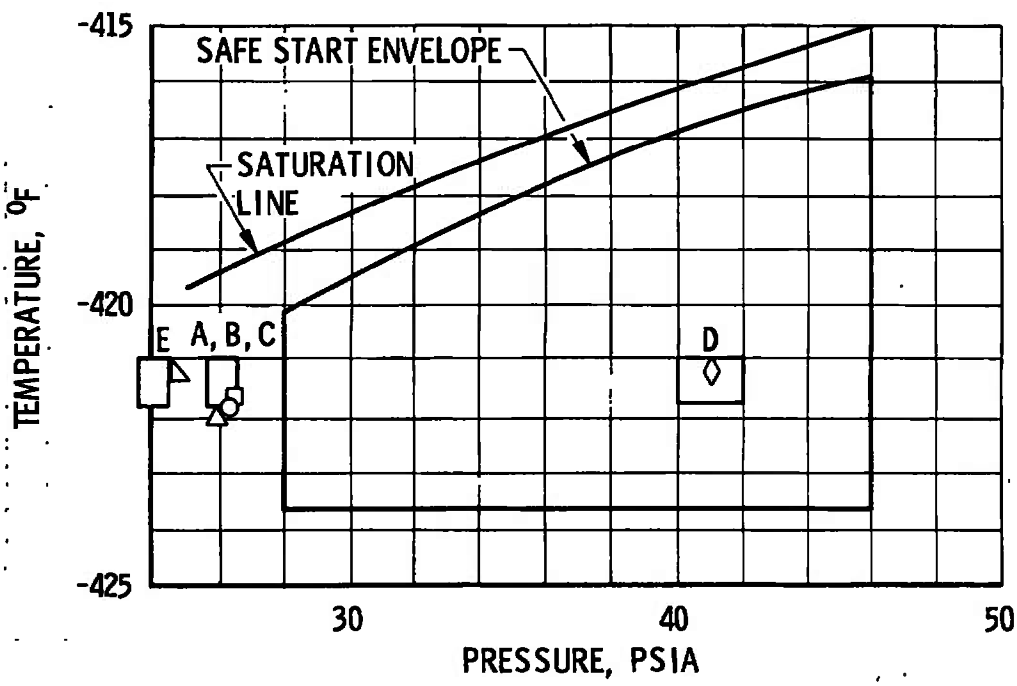
[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. Auxiliary Logic Start Sequence

Fig. 7 Concluded

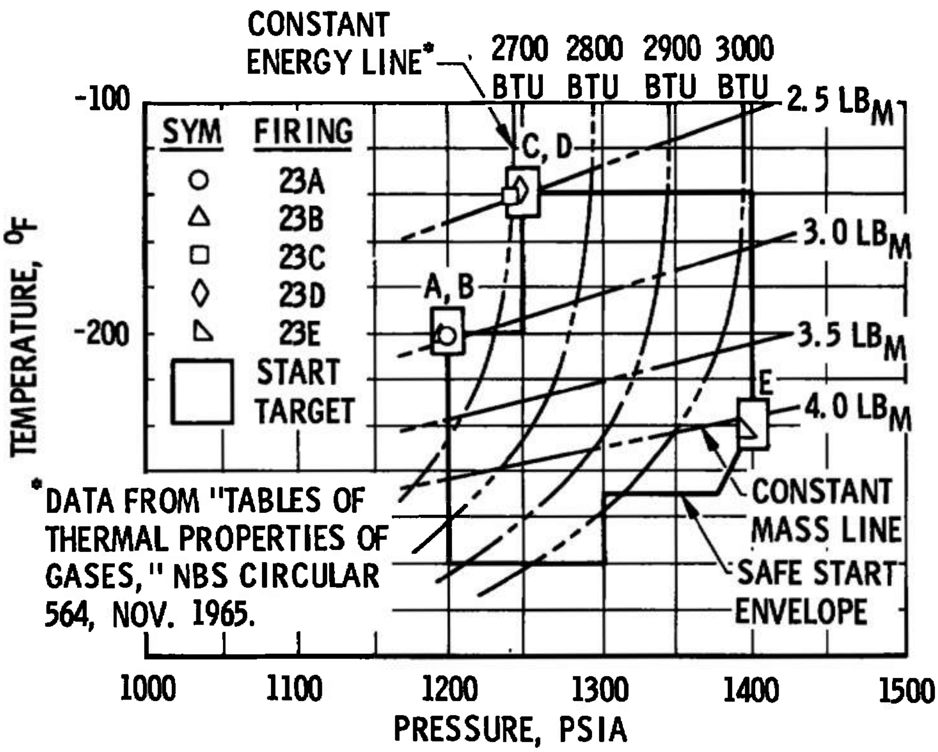


a. Oxidizer Pump Inlet

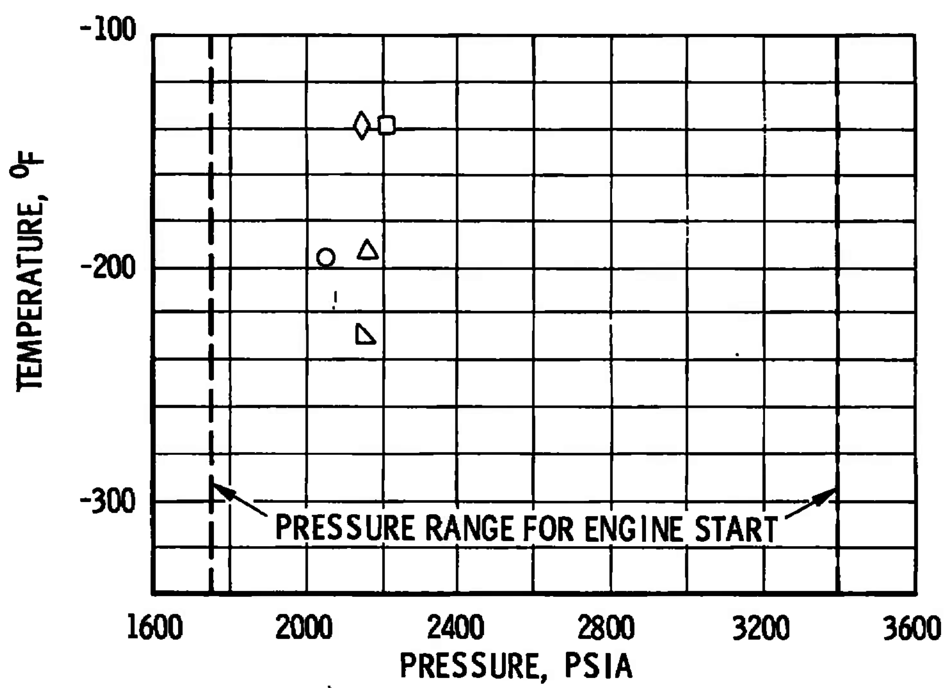


b. Fuel Pump Inlet

Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank

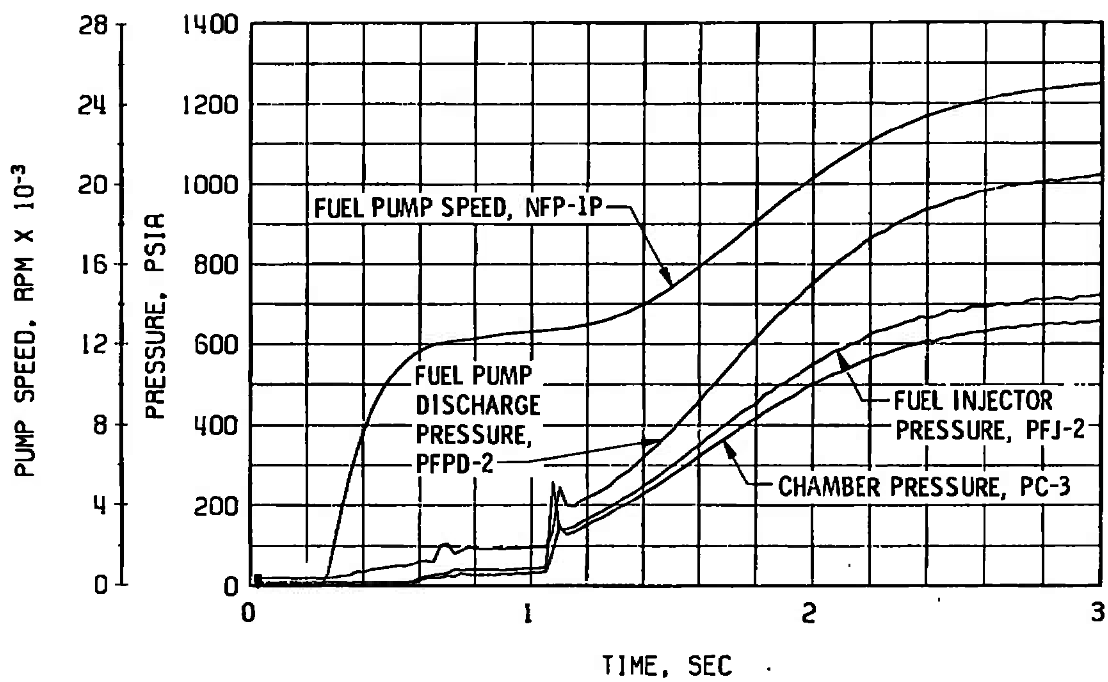


c. Start Tank

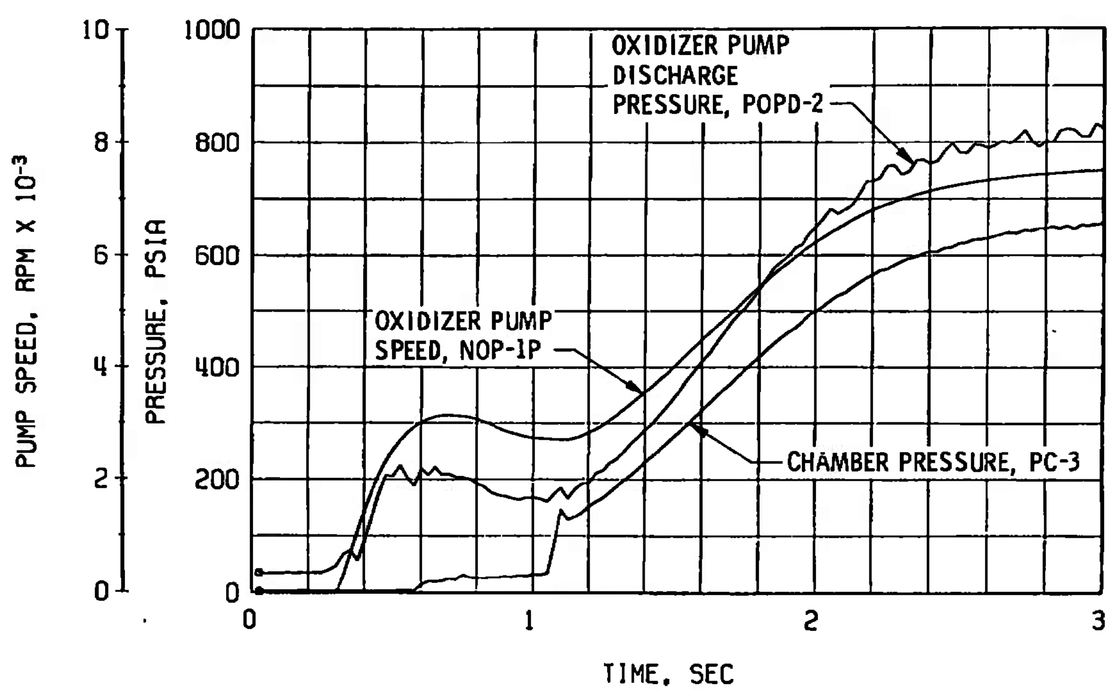


d. Helium Tank

Fig. 8 Concluded

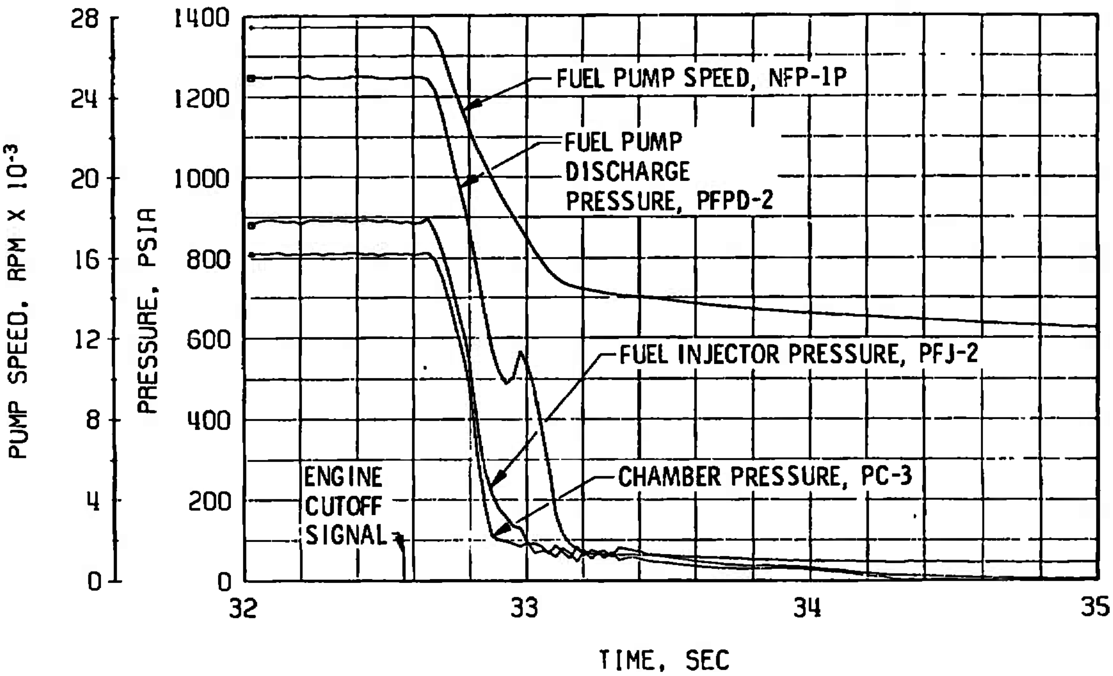


a. Thrust Chamber Fuel System, Start

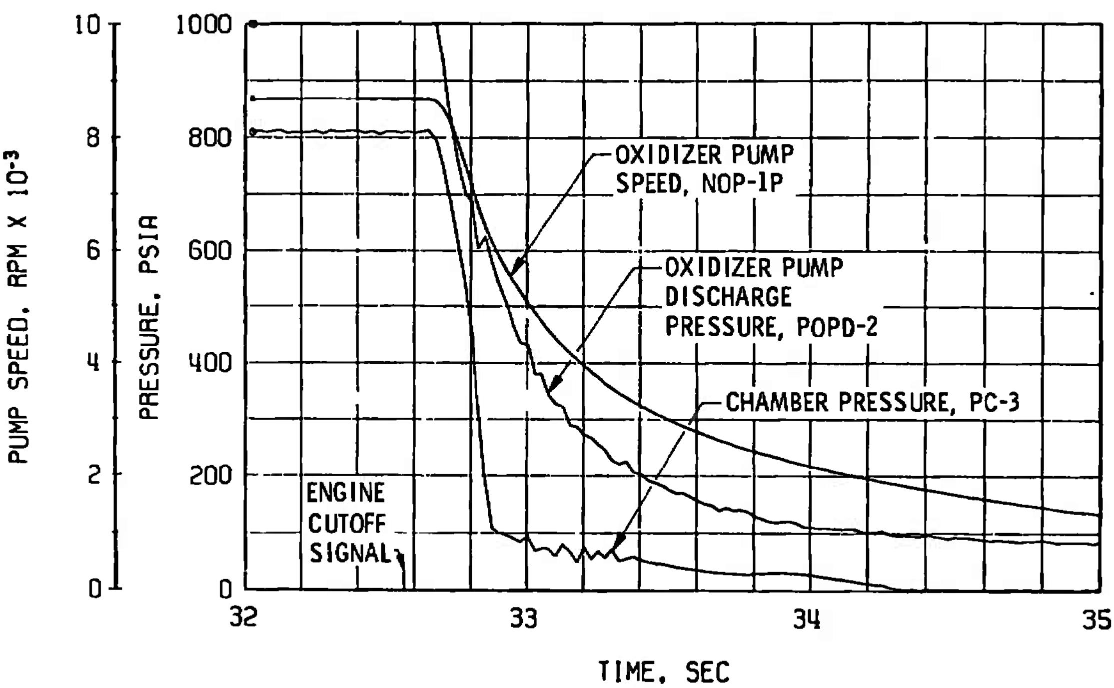


b. Thrust Chamber Oxidizer System, Start

Fig. 9 Engine Transient Operation, Firing 23A

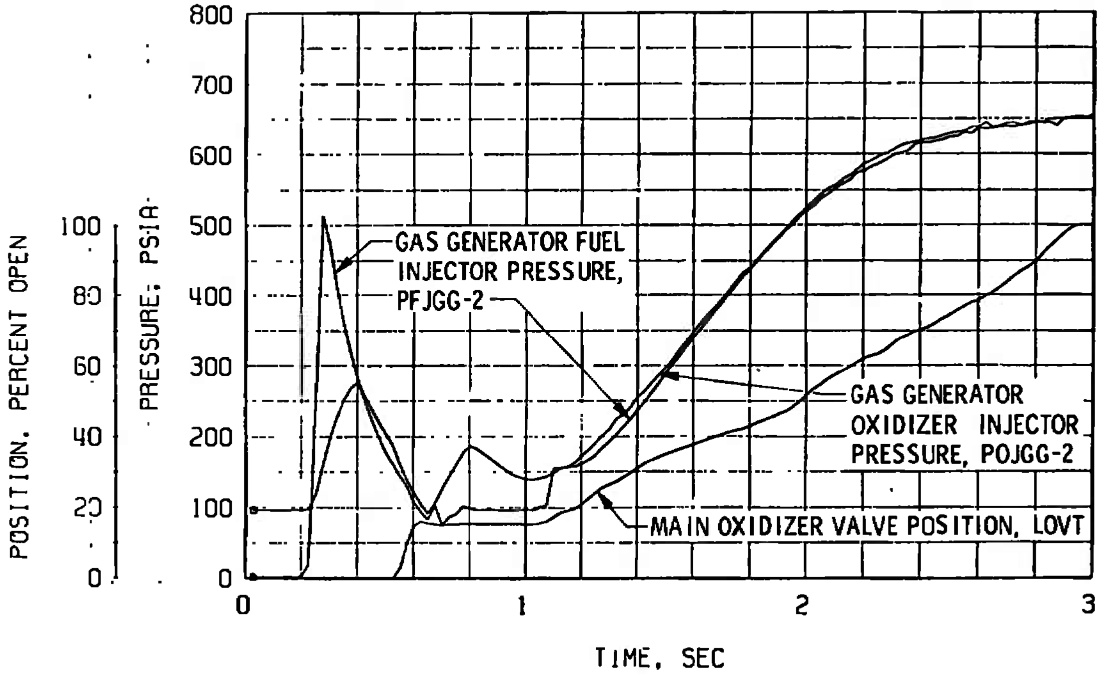


c. Thrust Chamber Fuel System, Shutdown

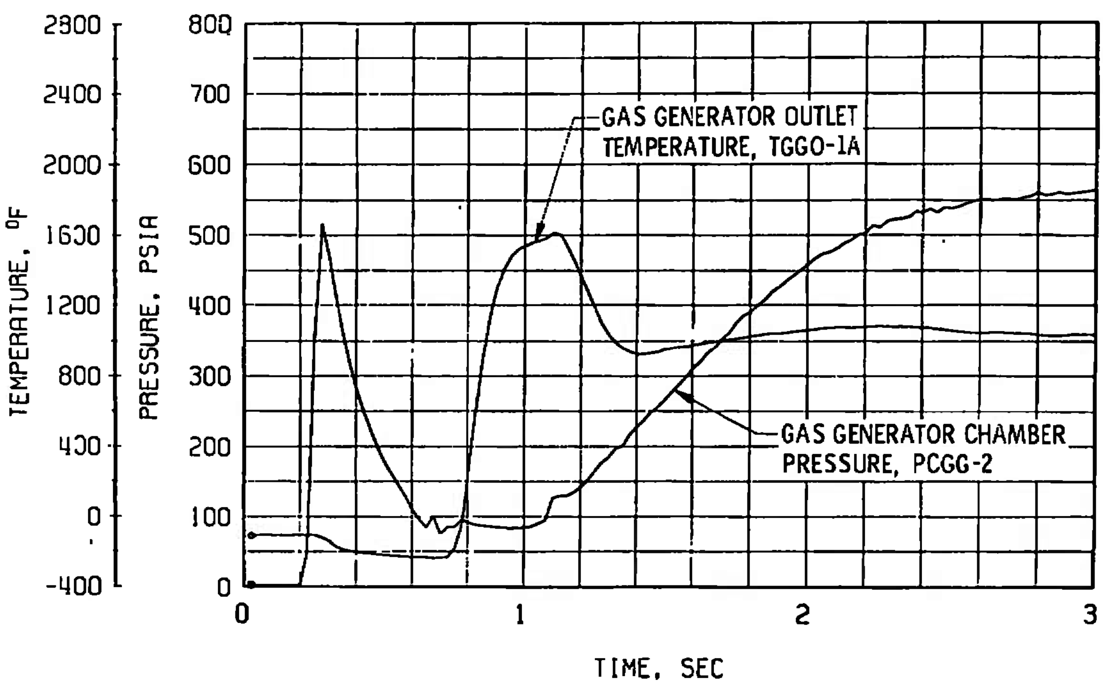


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 9 Continued

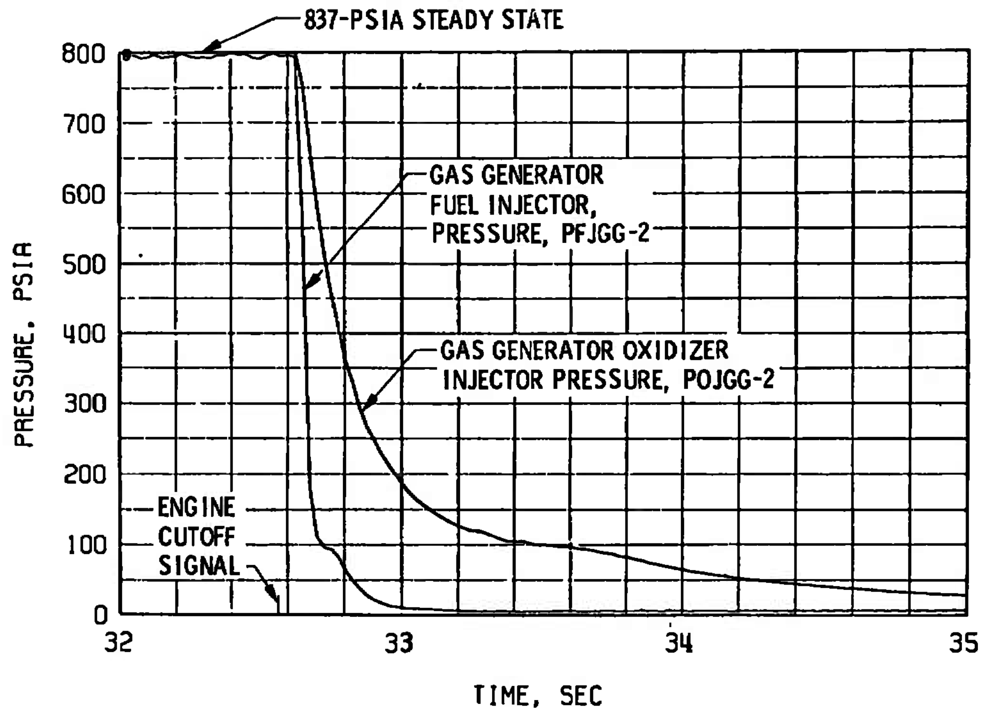


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

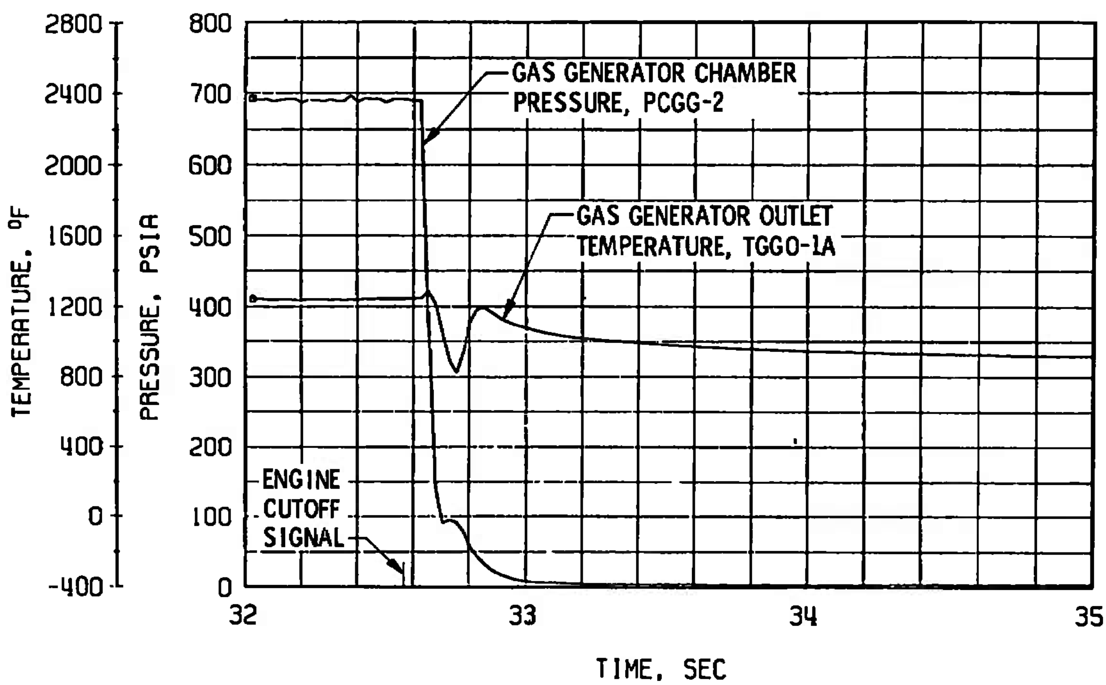


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 9 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 9 Concluded

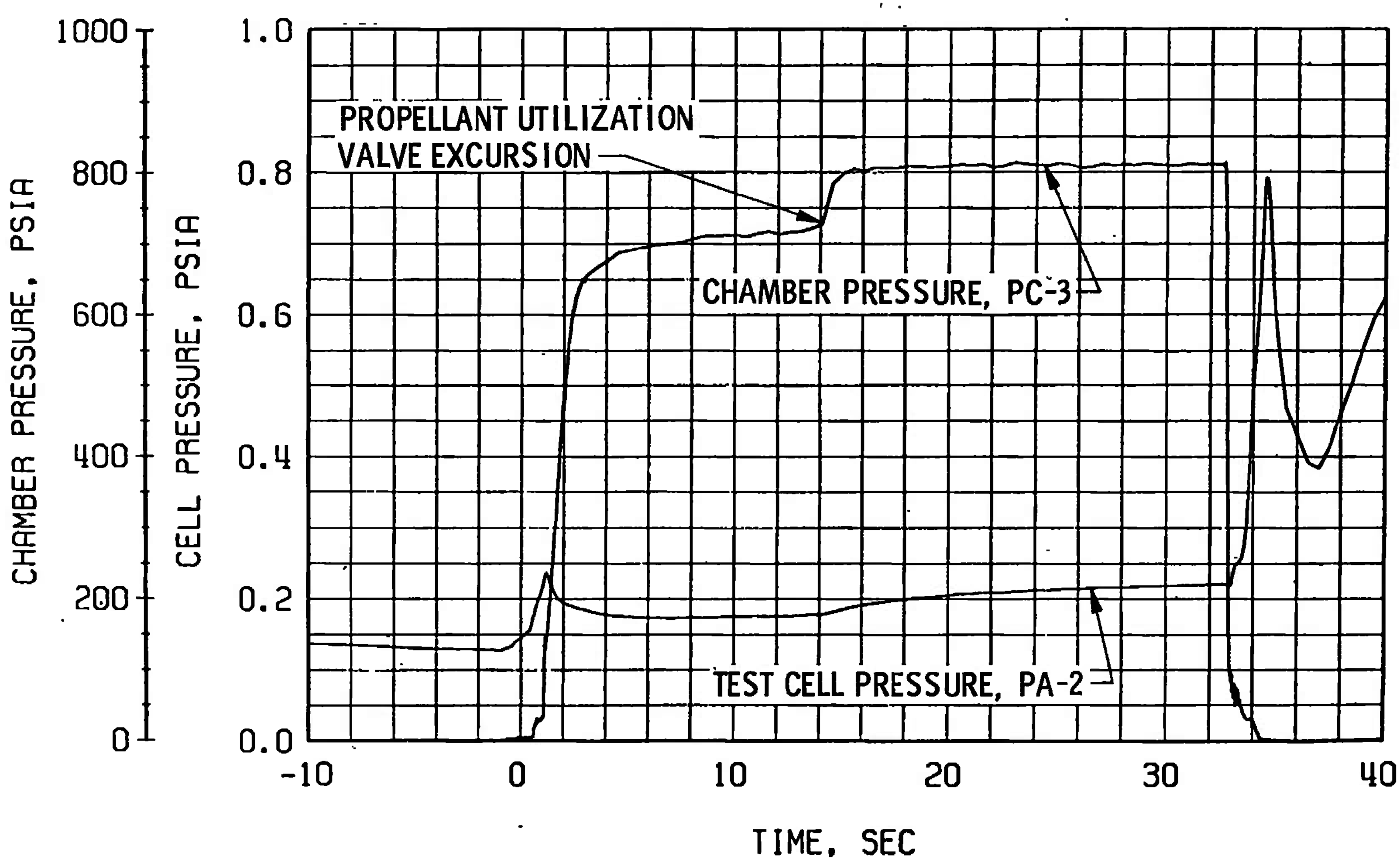
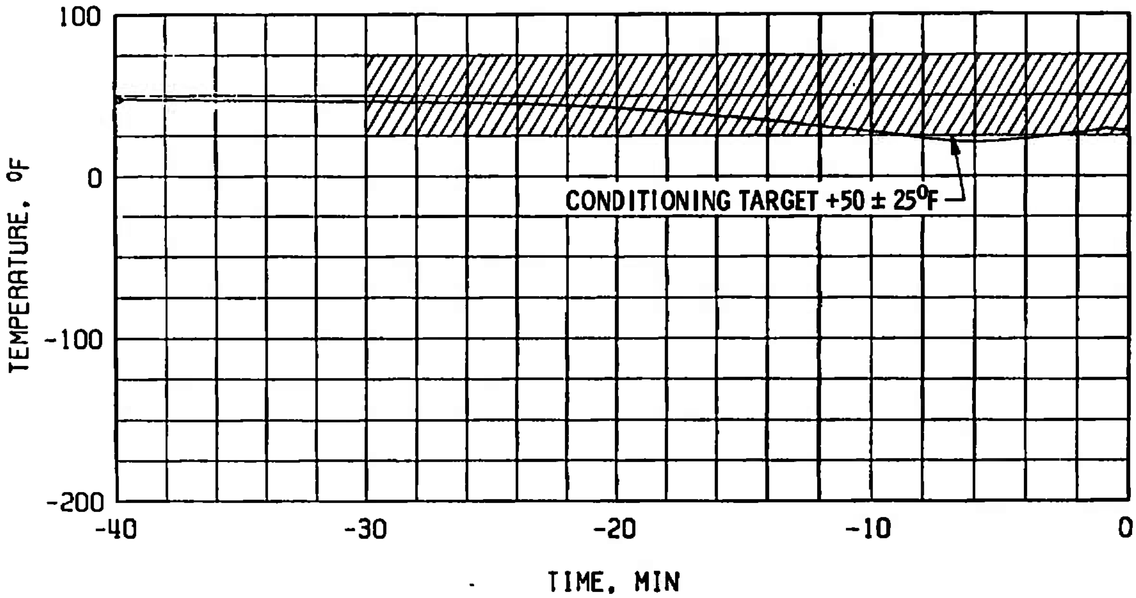
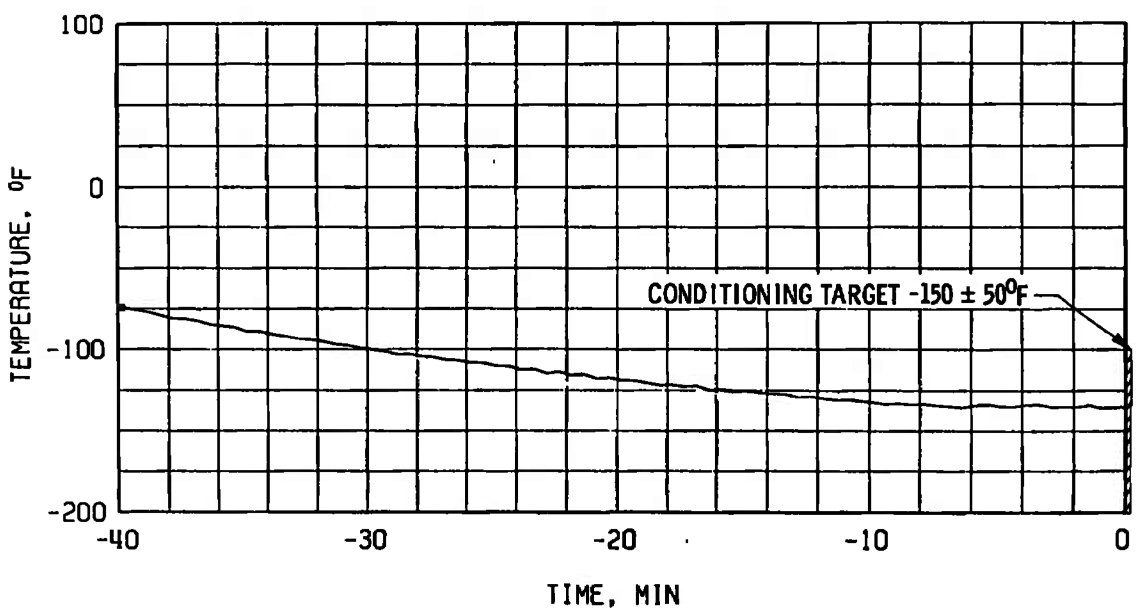


Fig. 10 Engine Ambient and Combustion Chamber Pressure, Firing 23A

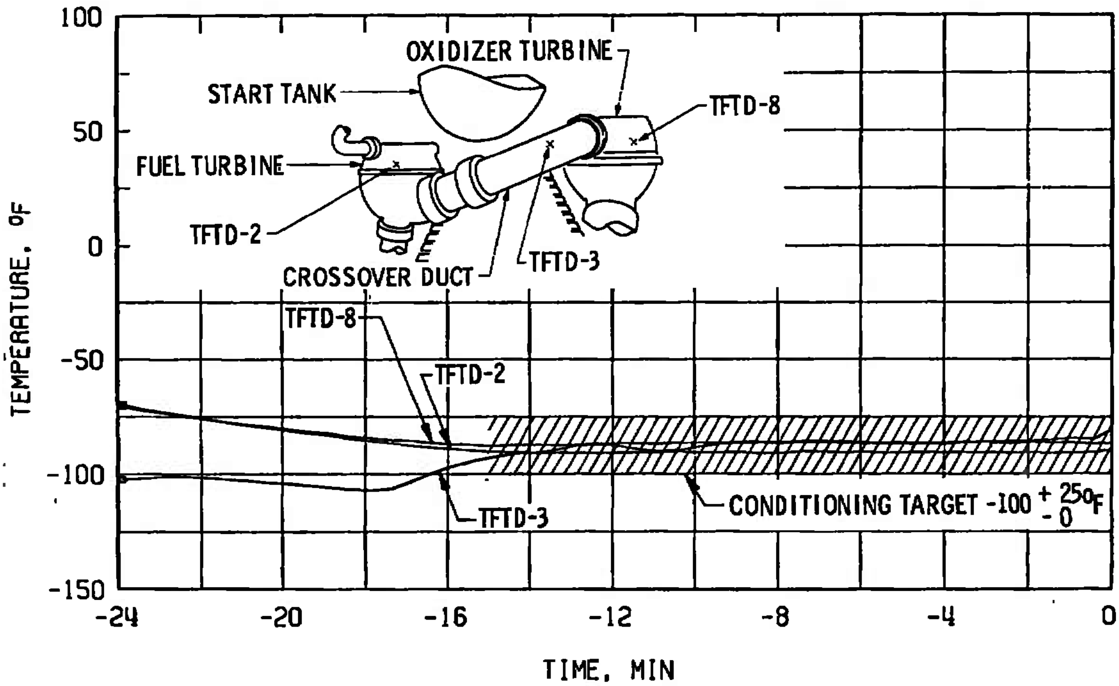


a. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

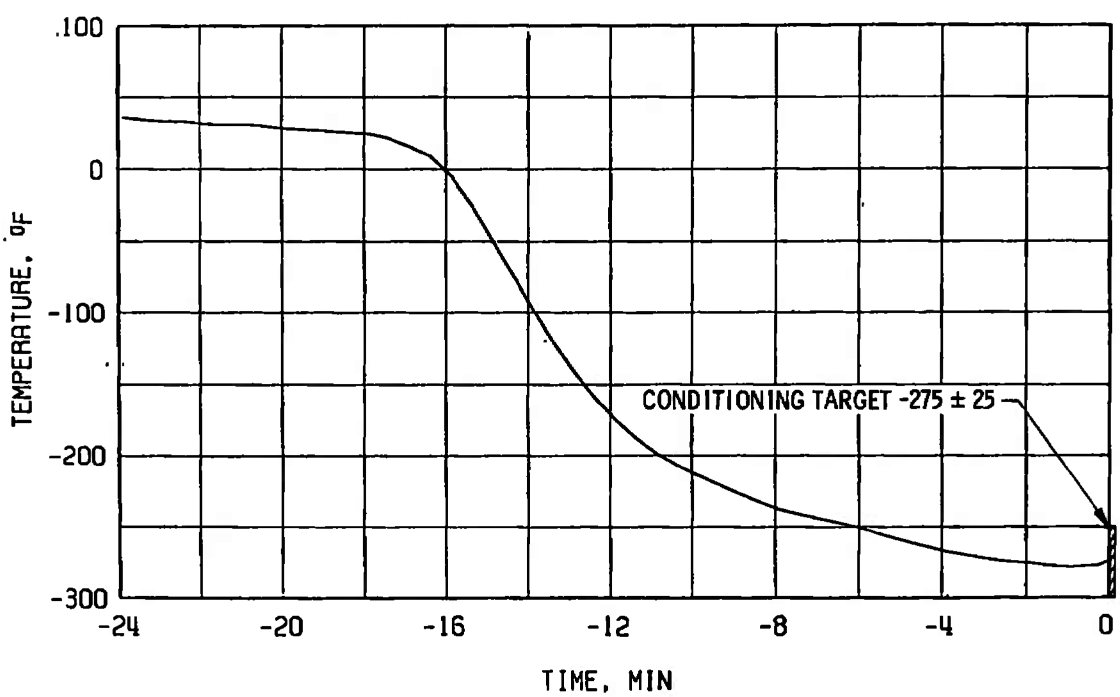


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC

Fig. 11 Thermal Conditioning History of Engine Components, Firing 23A



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 11 Concluded

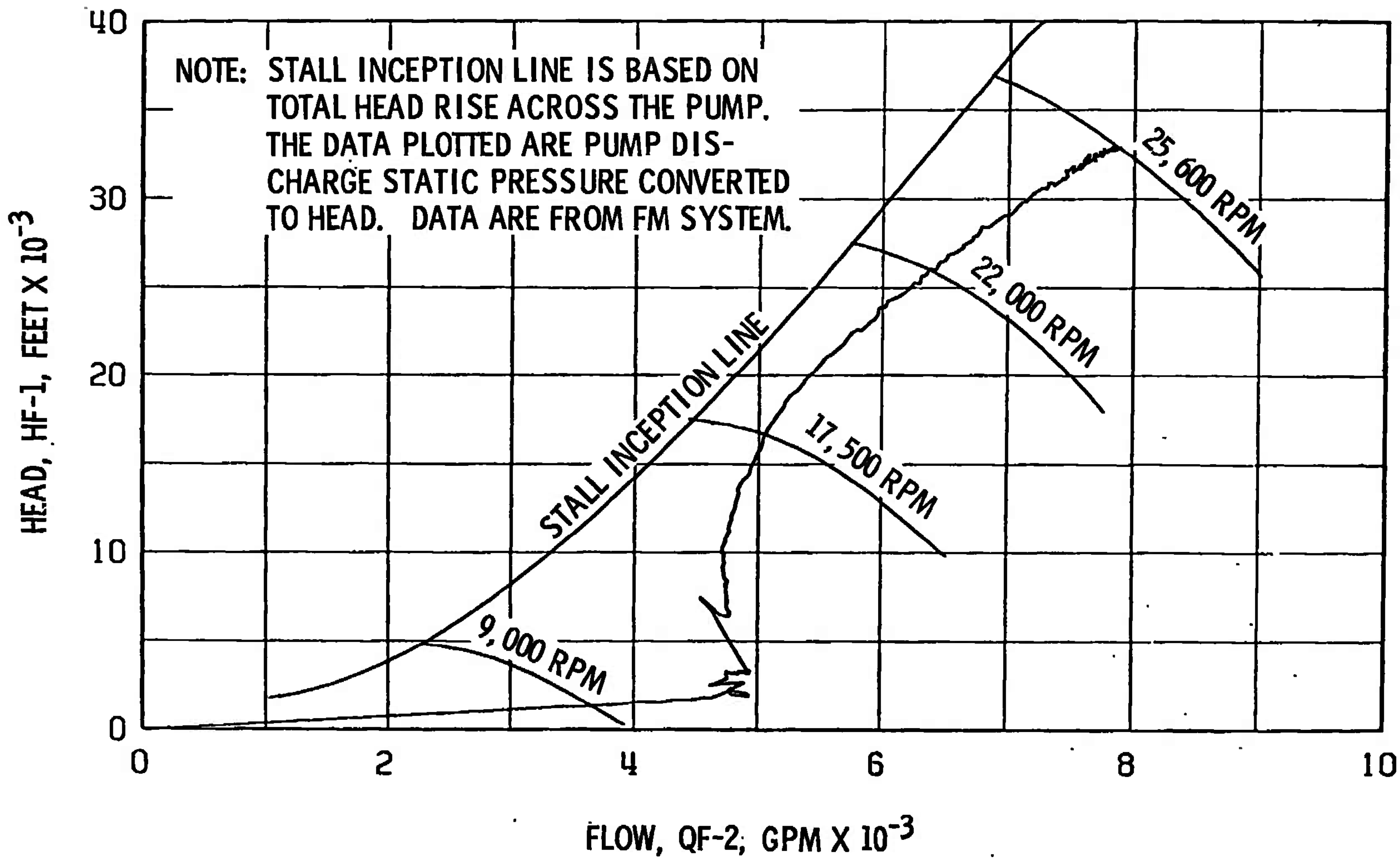
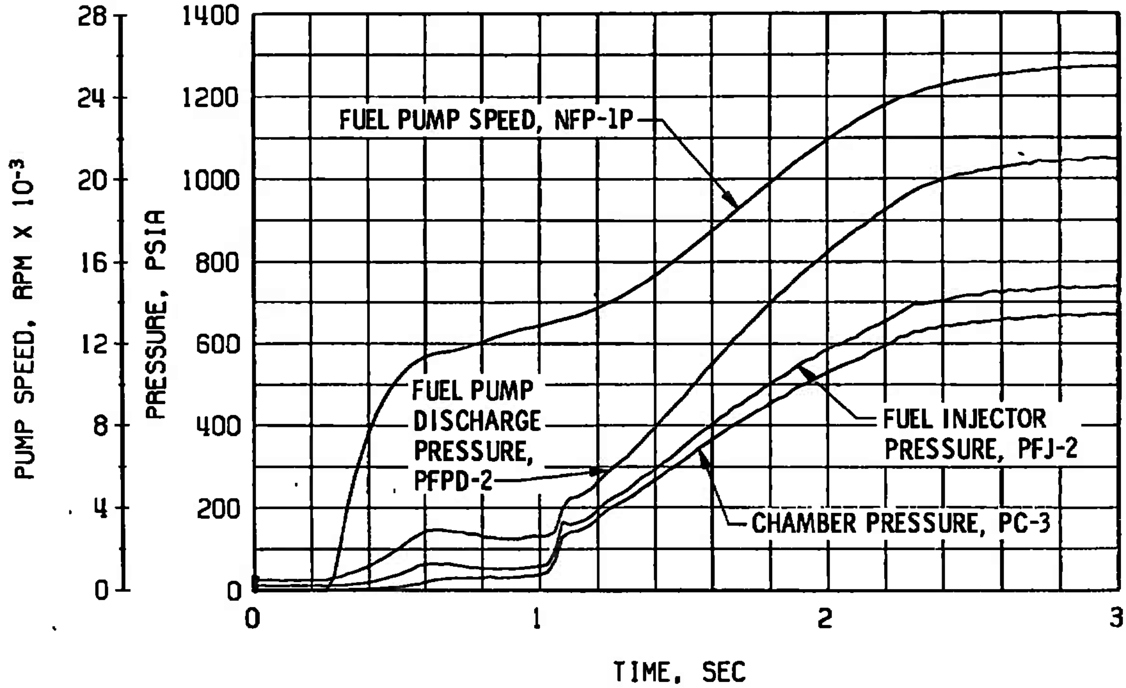
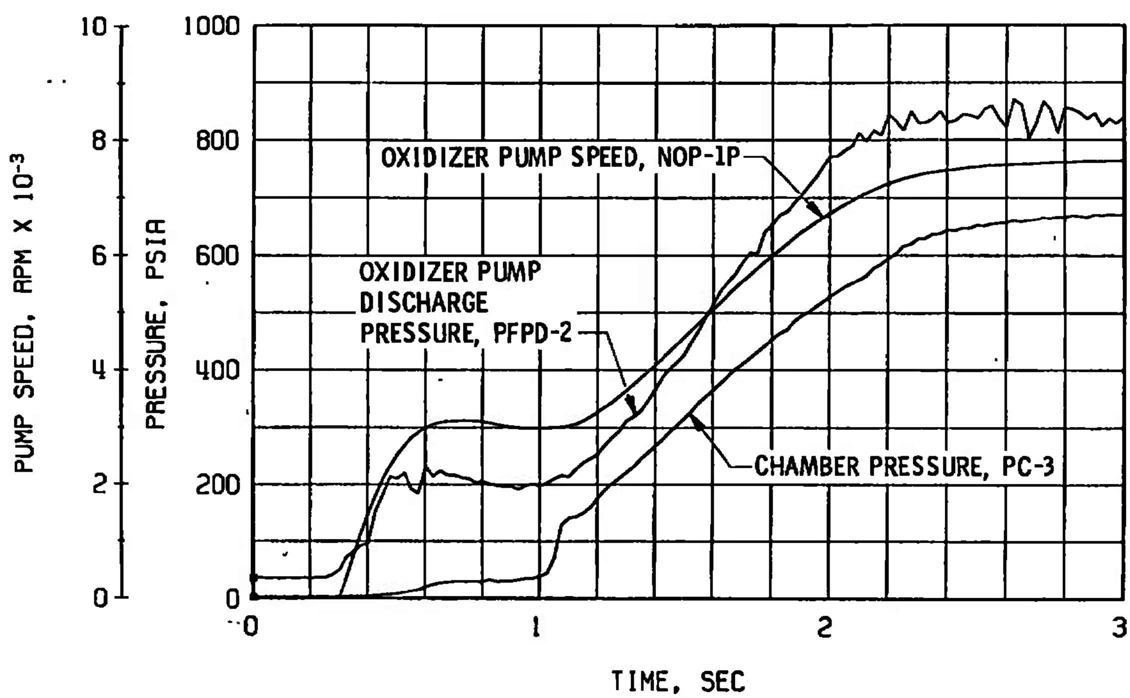


Fig. 12 Fuel Pump Start Transient Performance, Firing 23A

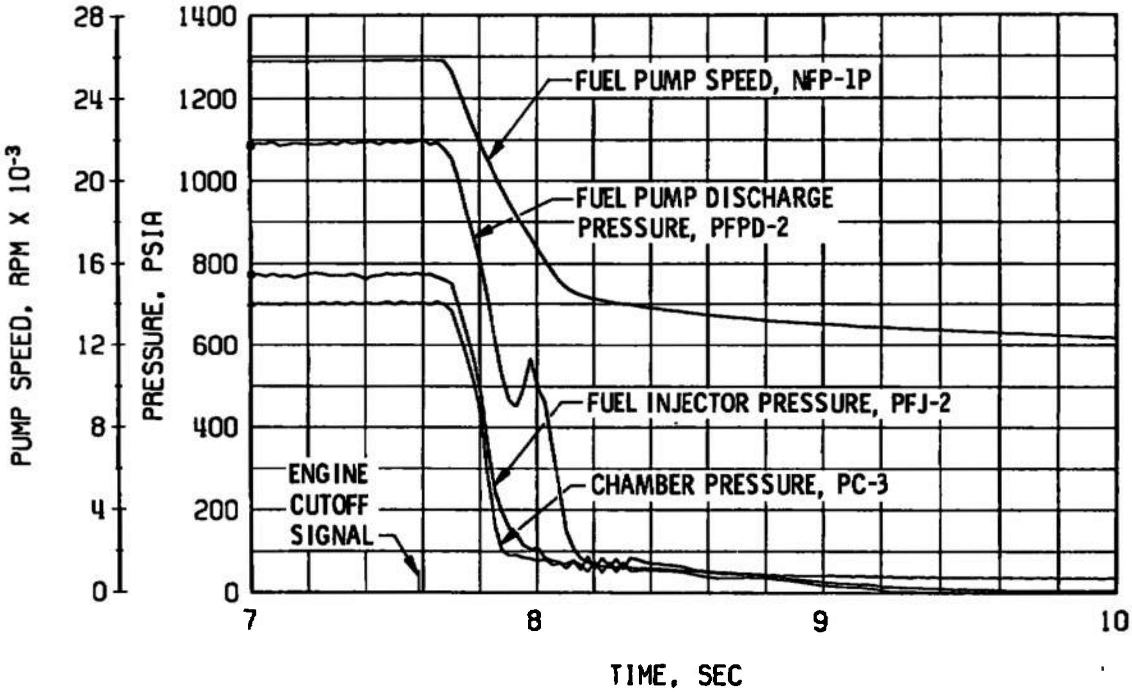


a. Thrust Chamber Fuel System, Start

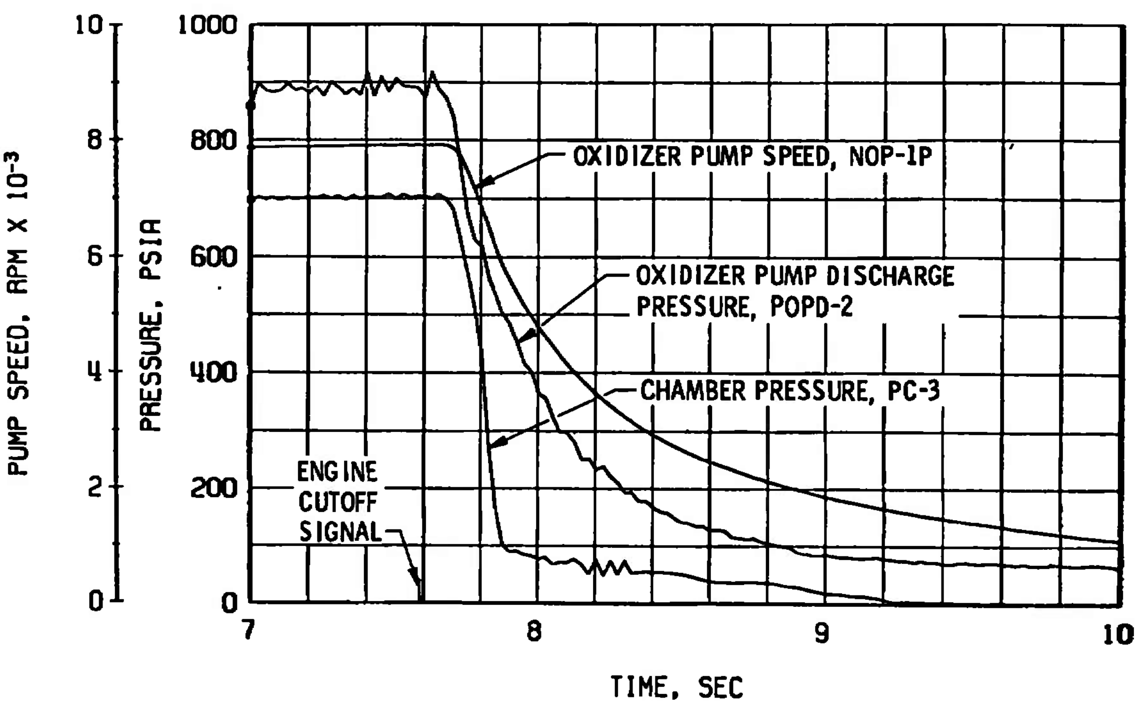


b. Thrust Chamber Oxidizer System, Start

Fig. 13 Engine Transient Operation, Firing 23B

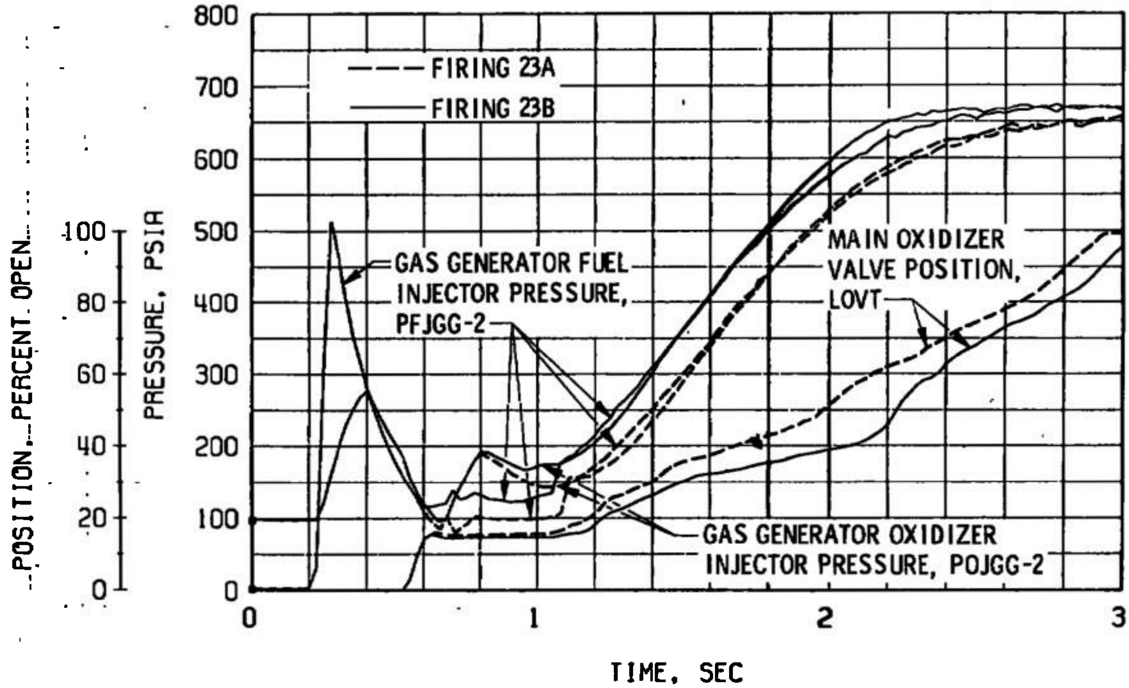


c. Thrust Chamber Fuel System, Shutdown

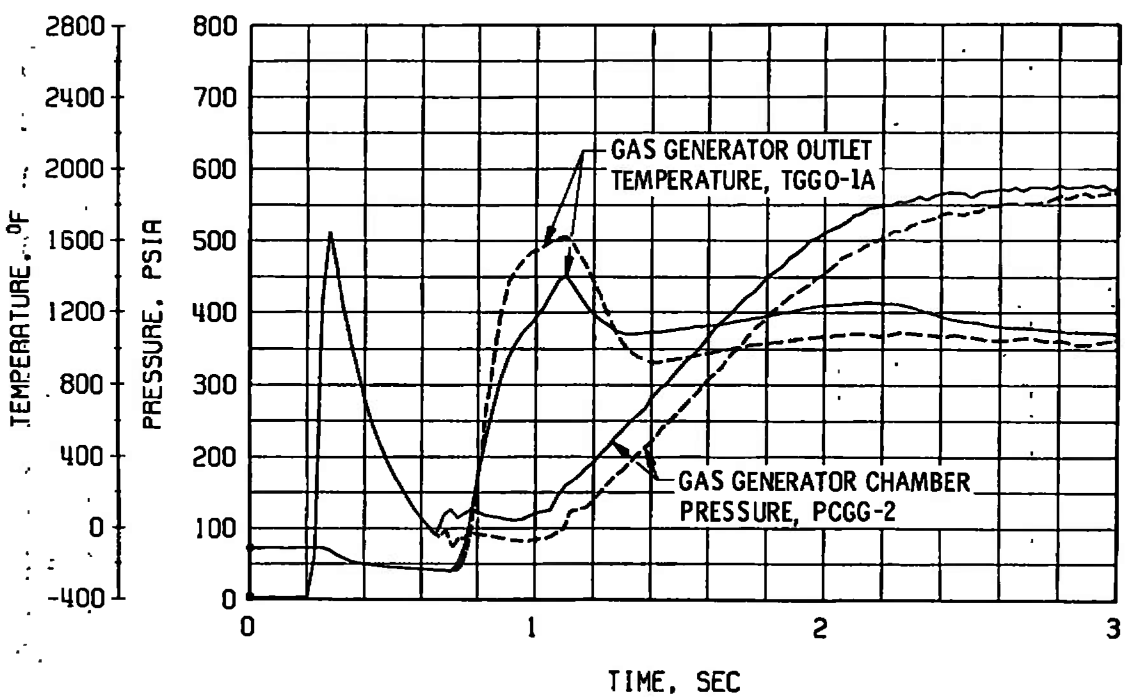


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 13 Continued

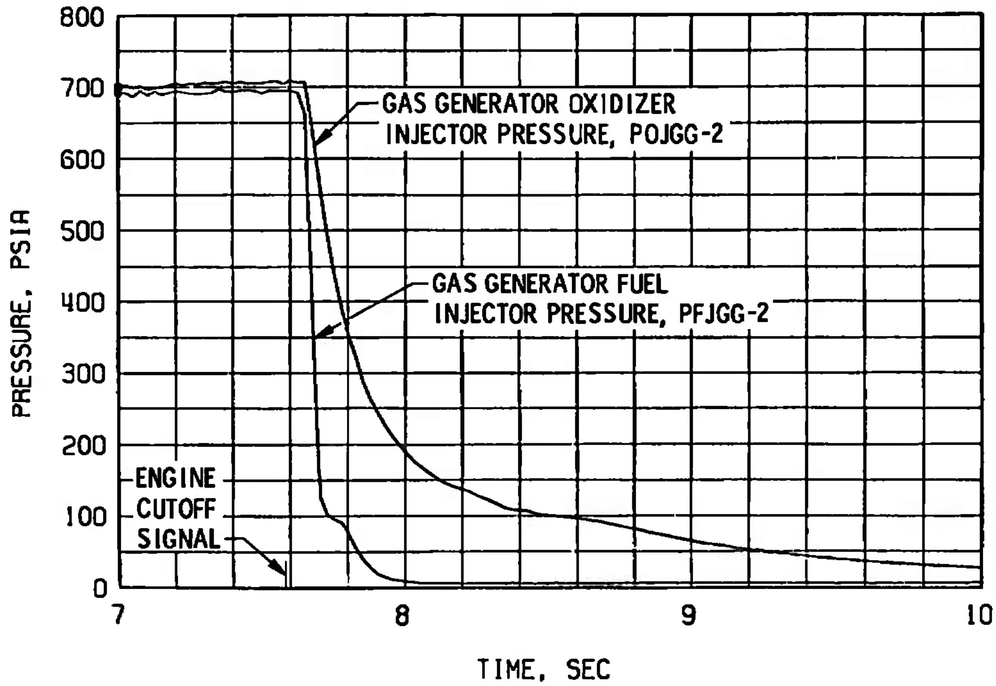


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start, Comparison of Firings 23A and 23B

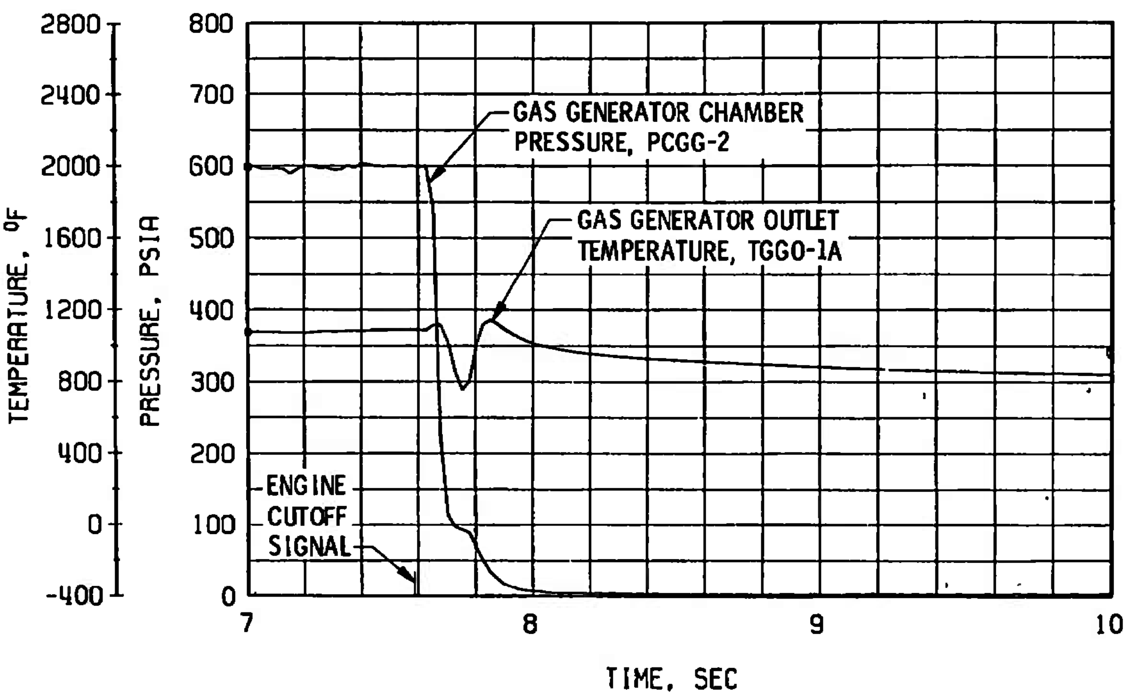


f. Gas Generator Chamber Pressure and Temperature, Start, Comparison of Firings 23A and 23B

Fig. 13 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 13 Concluded

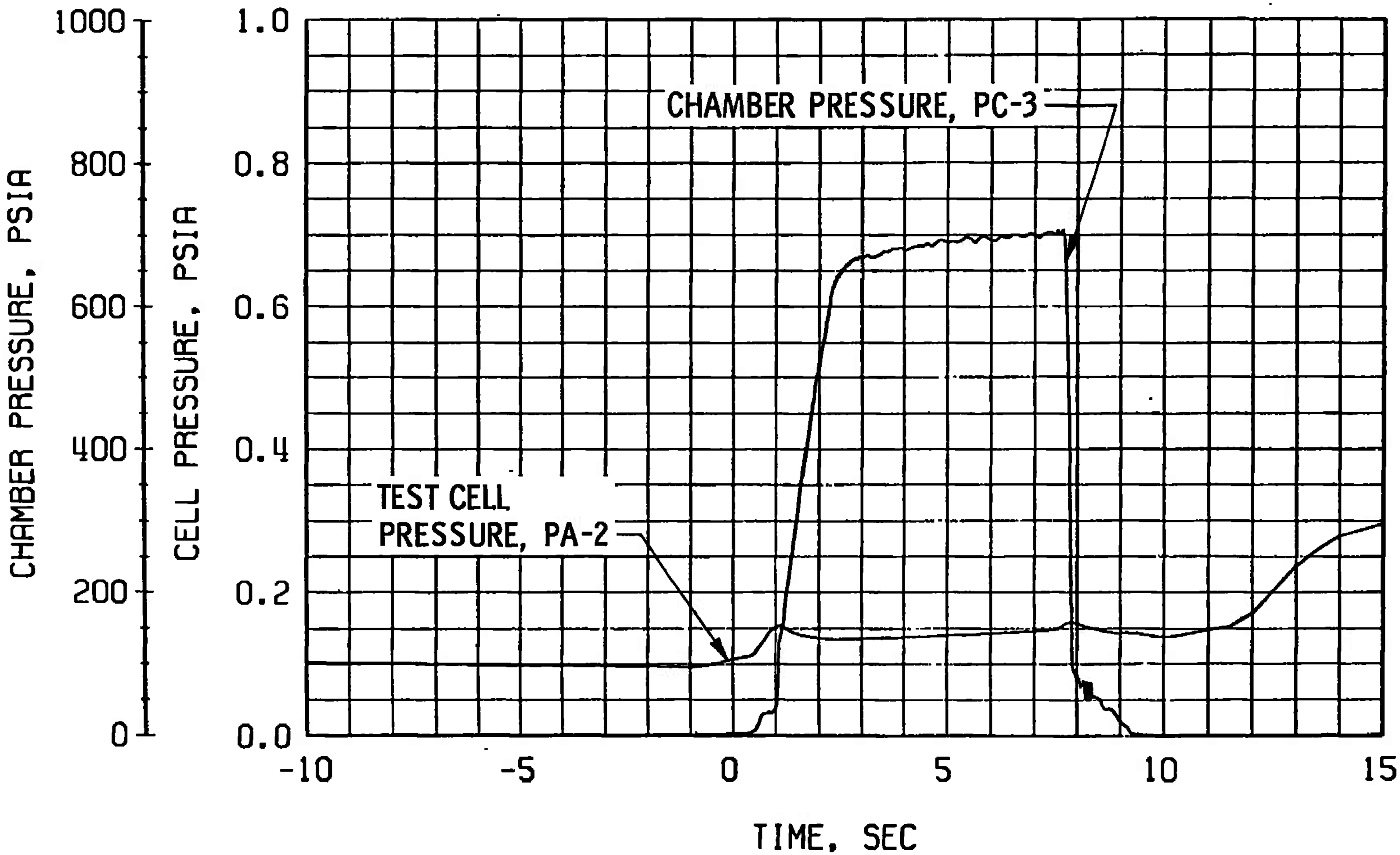
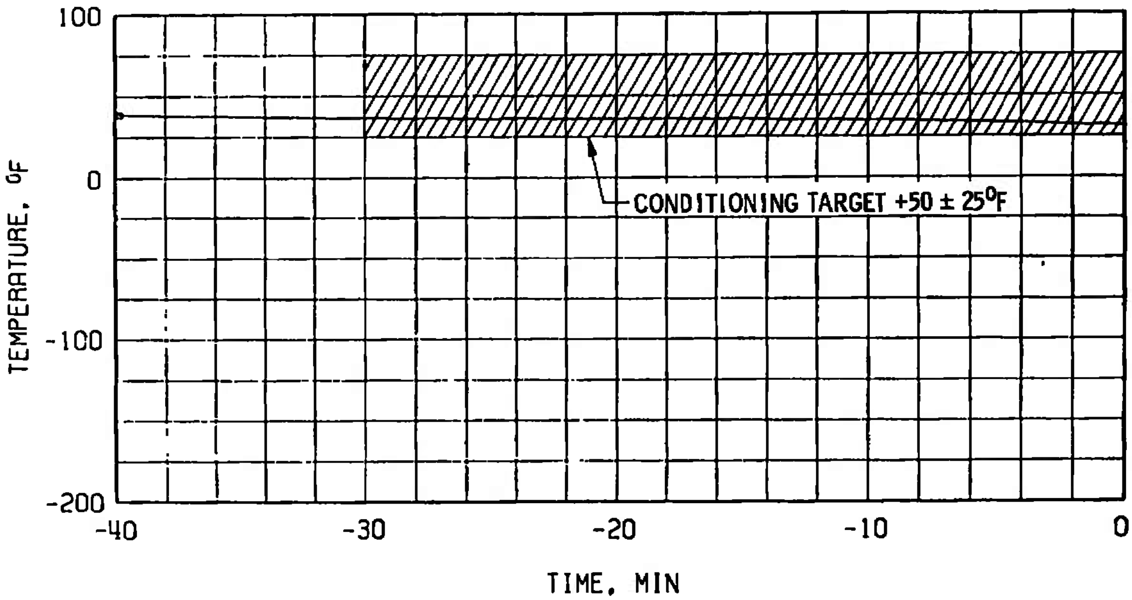
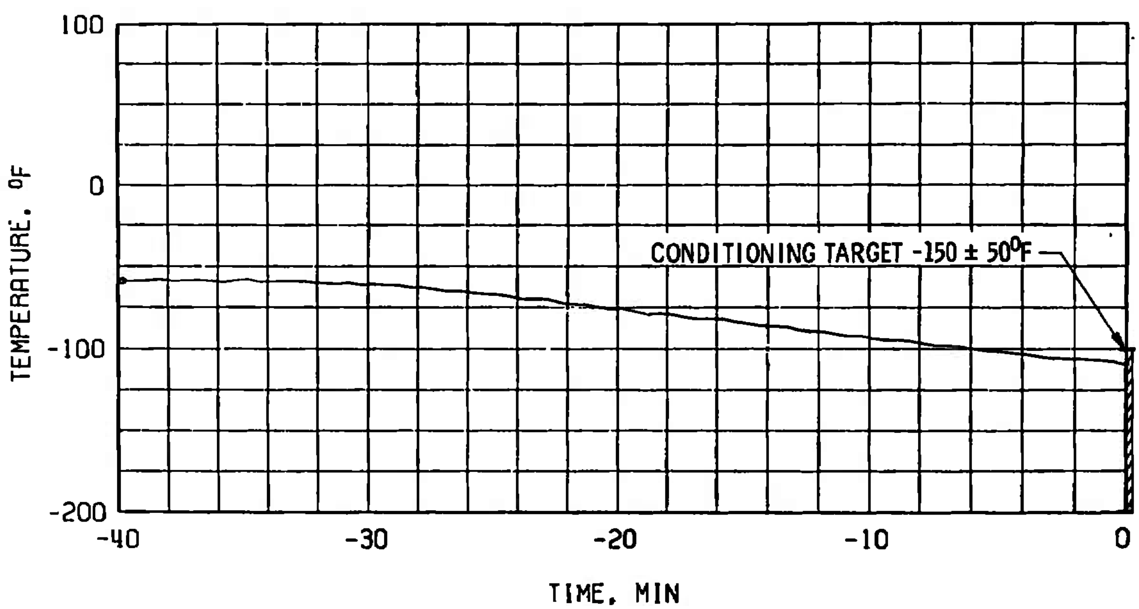


Fig. 14 Engine Ambient and Combustion Chamber Pressure, Firing 23B

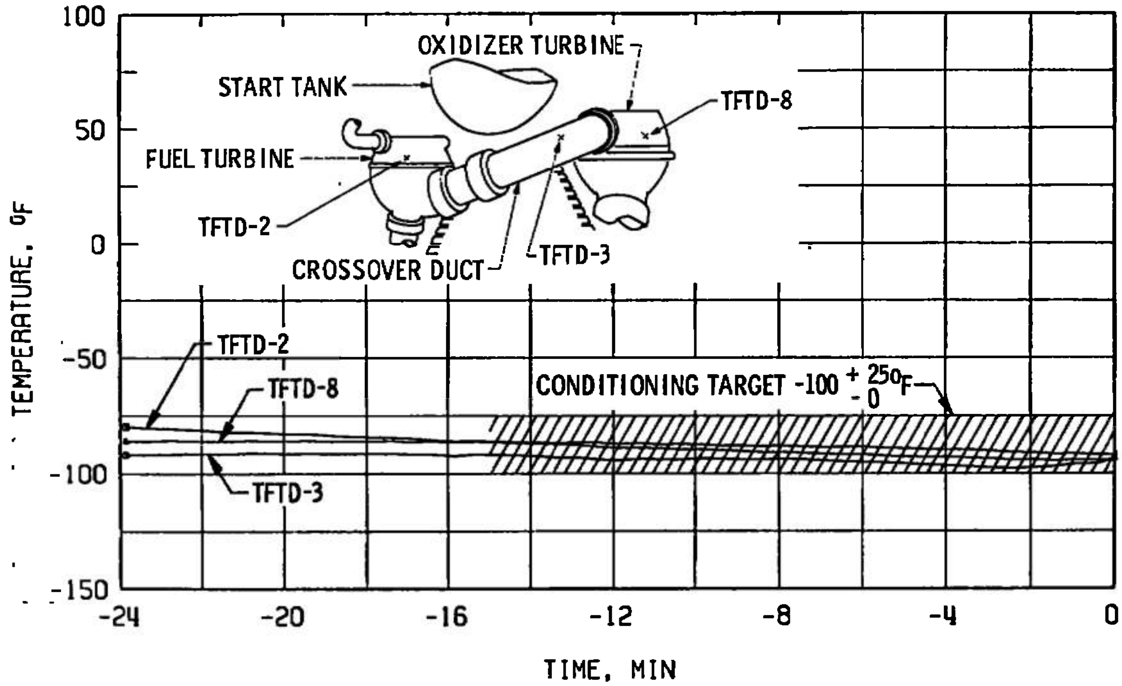


a. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

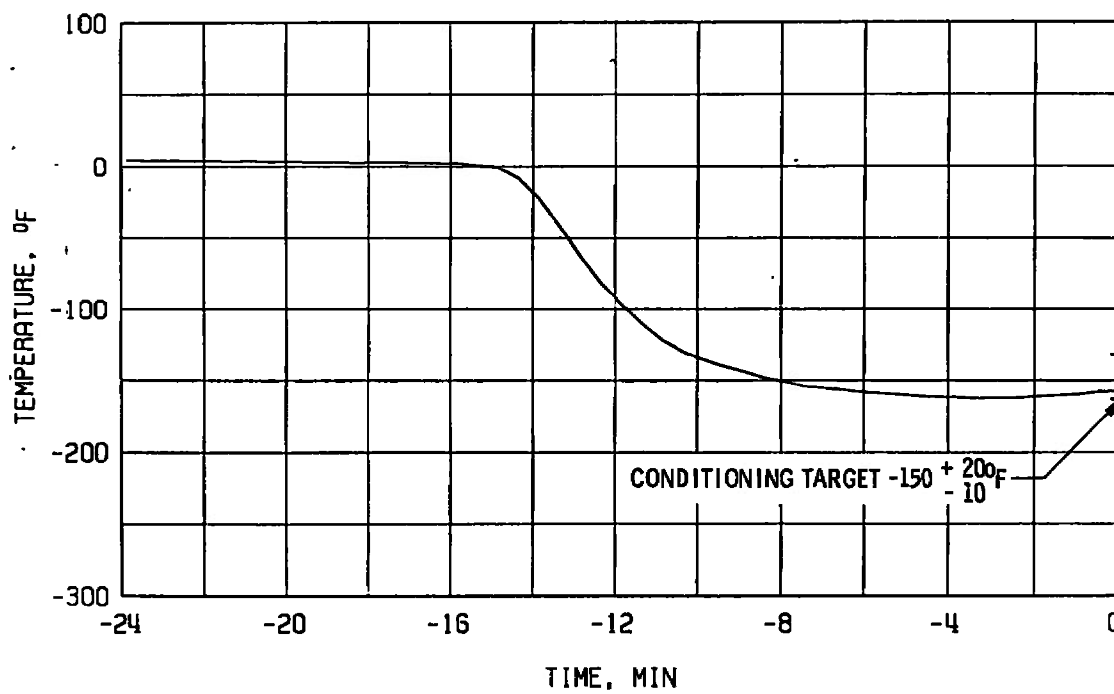


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 15 Thermal Conditioning History of Engine Components, Firing 23B



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 15 Concluded

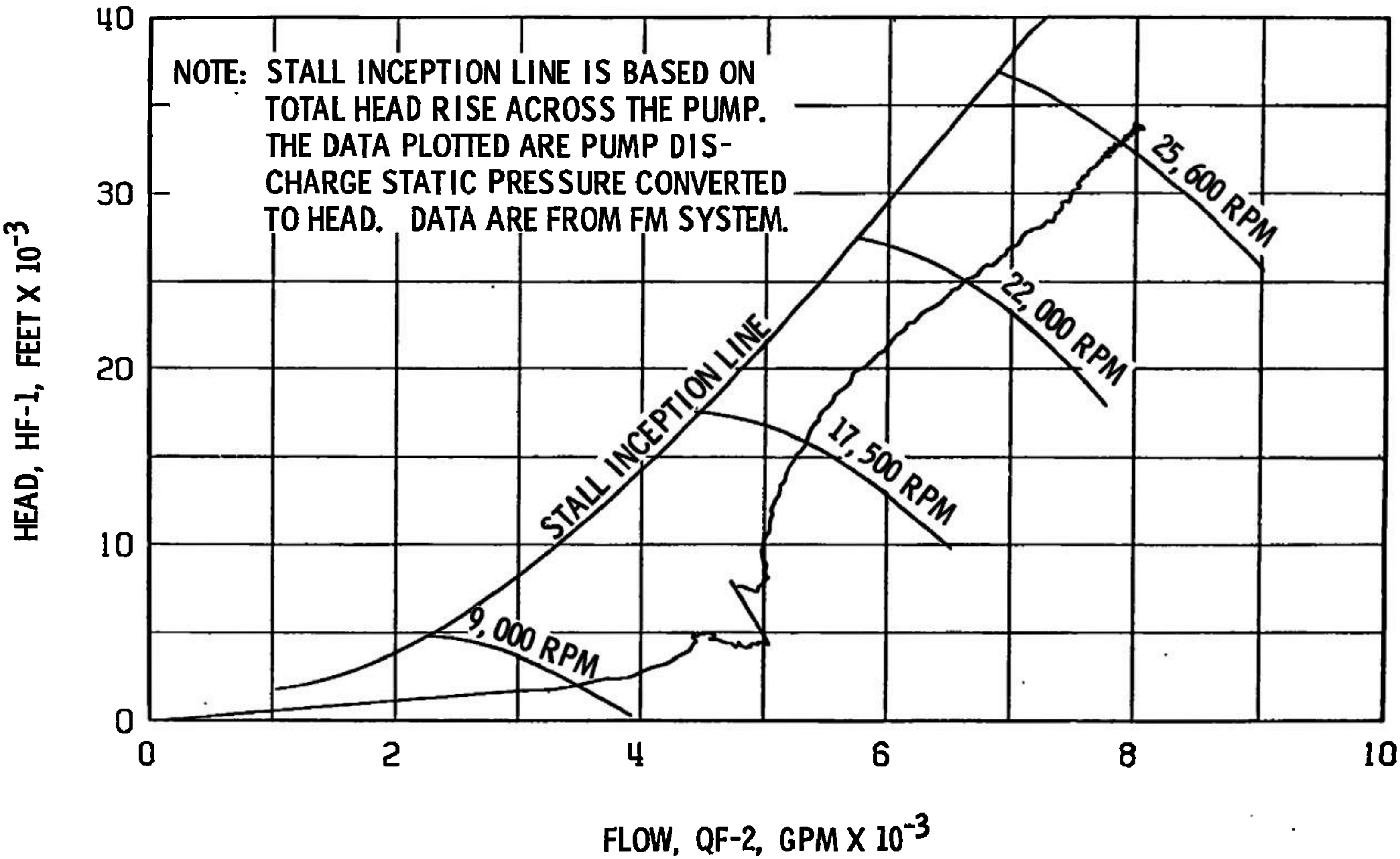


Fig. 16 Fuel Pump Start Transient Performance, Firing 23B

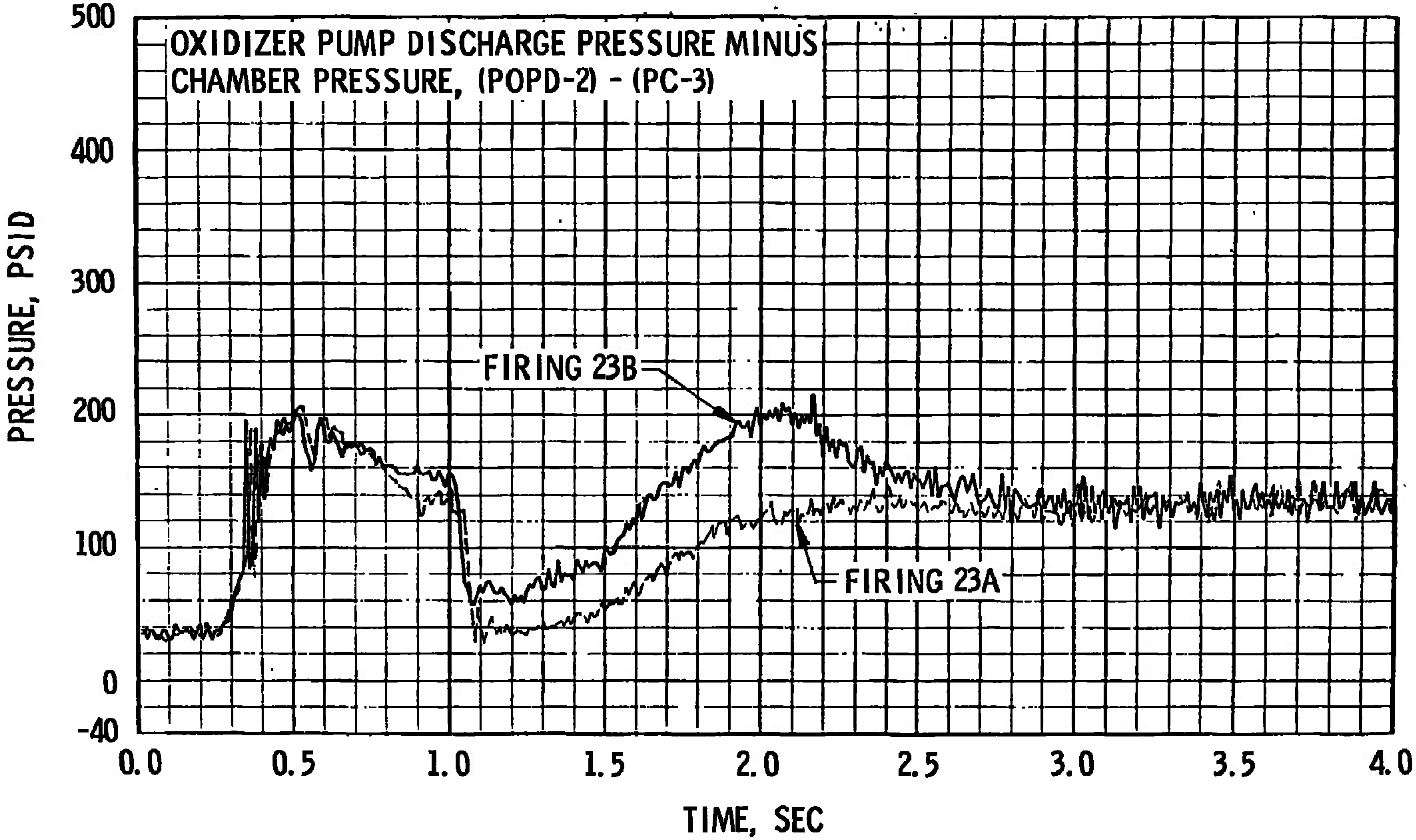
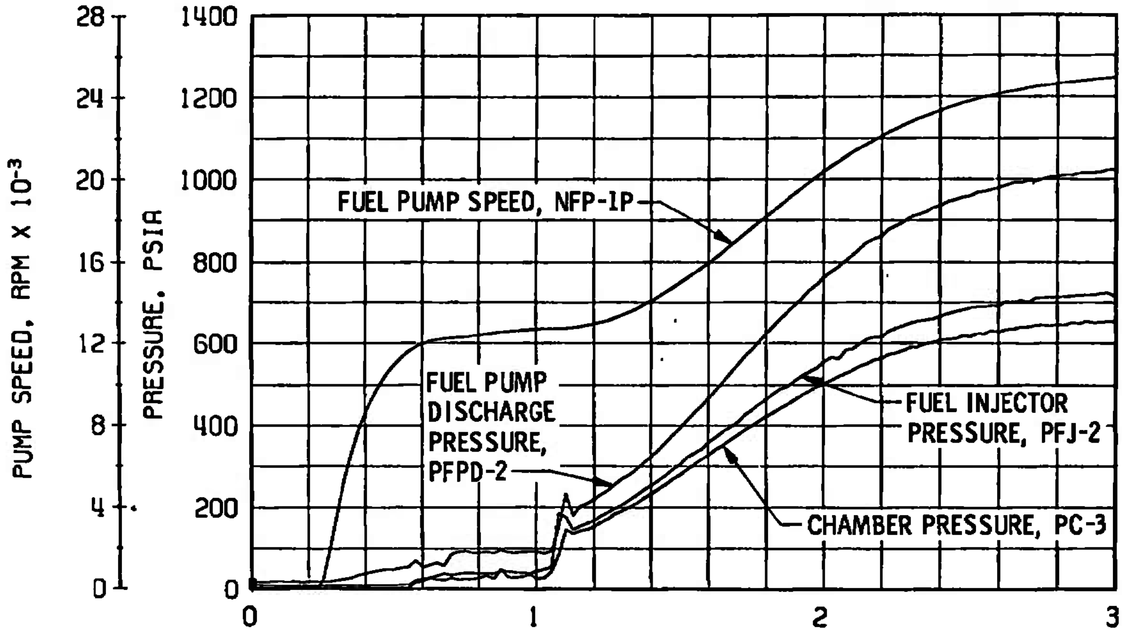
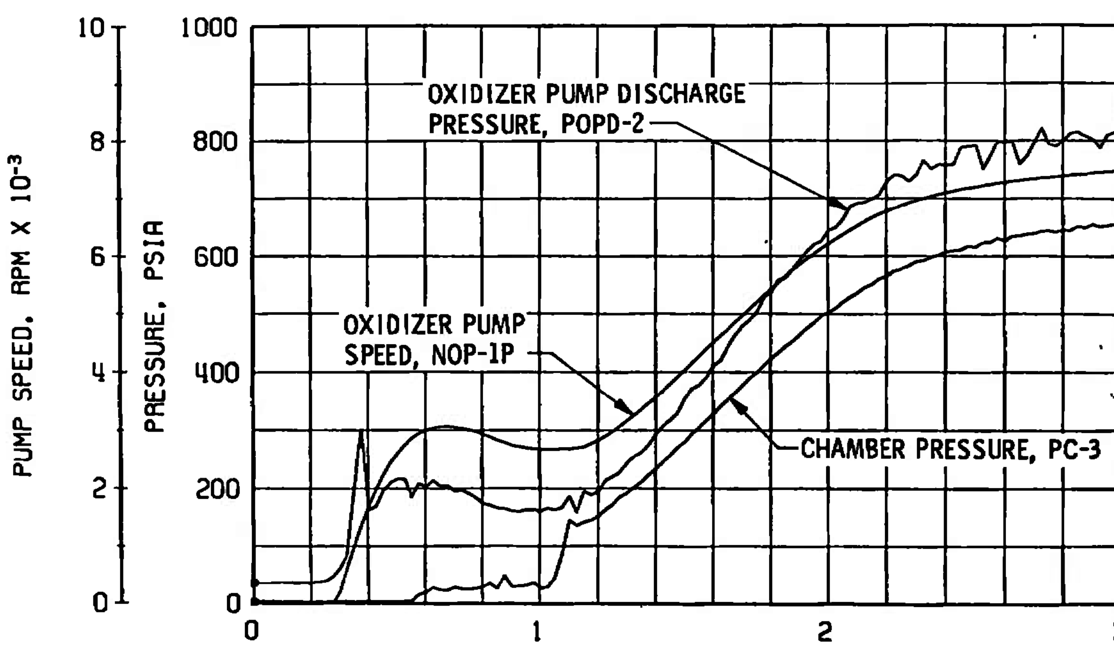


Fig. 17 Differential Pressure across Main Oxidizer Valve, Comparison of Firings 23A and 23B

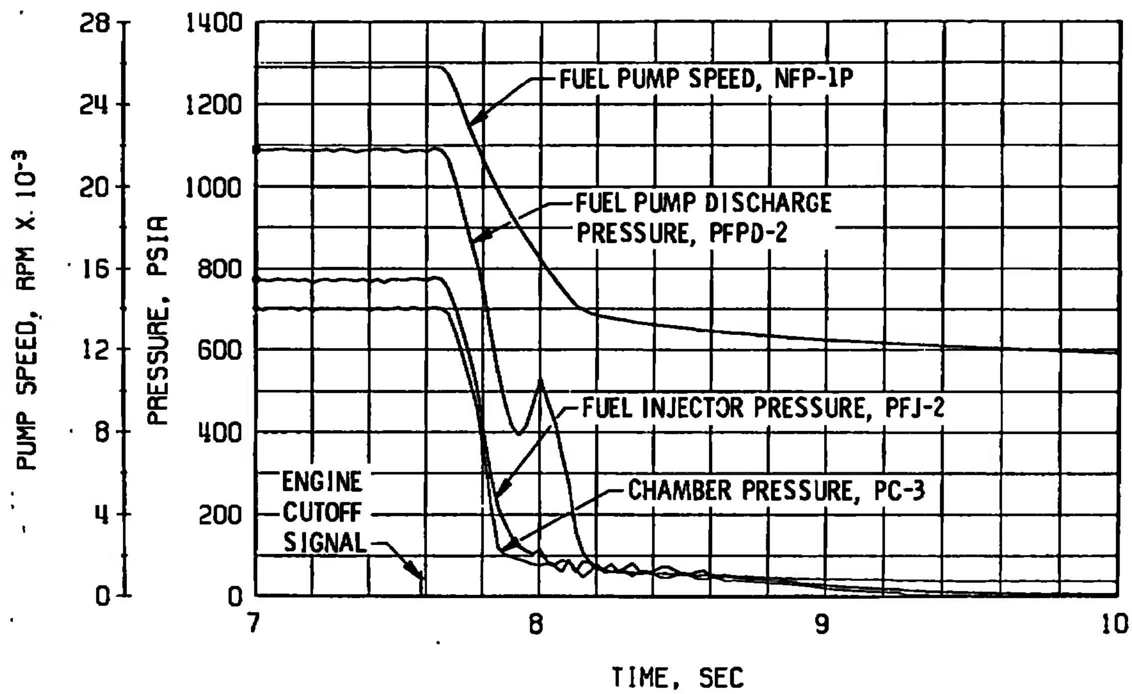


a. Thrust Chamber Fuel System, Start

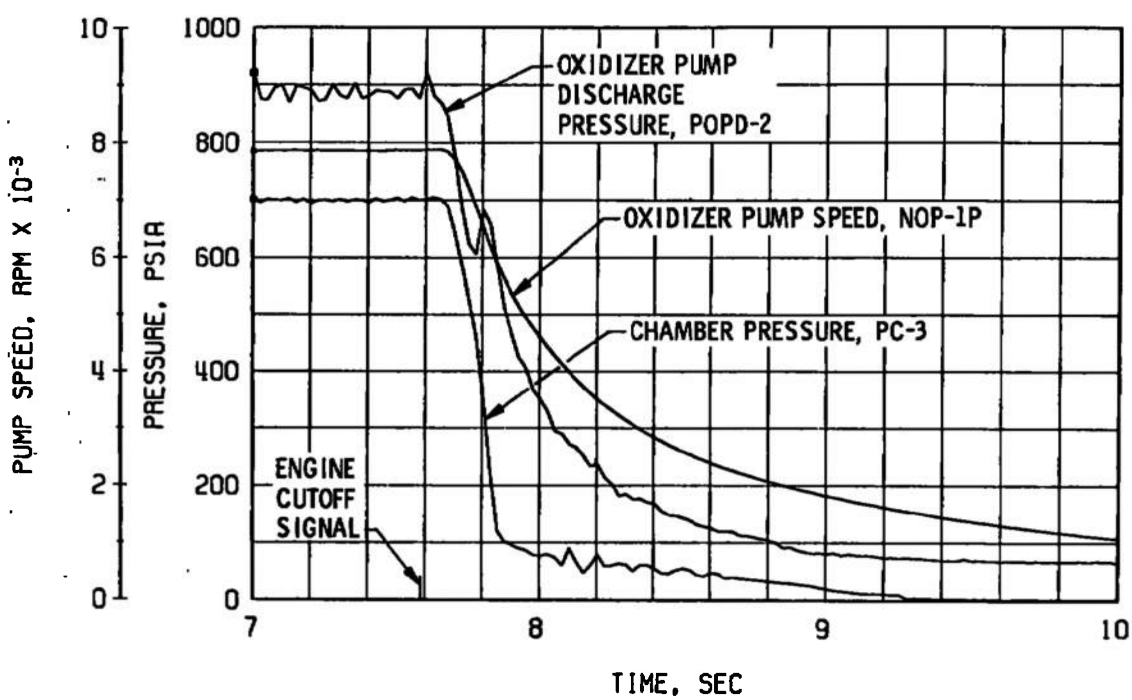


b. Thrust Chamber Oxidizer System, Start

Fig. 18 Engine Transient Operation, Firing 23C

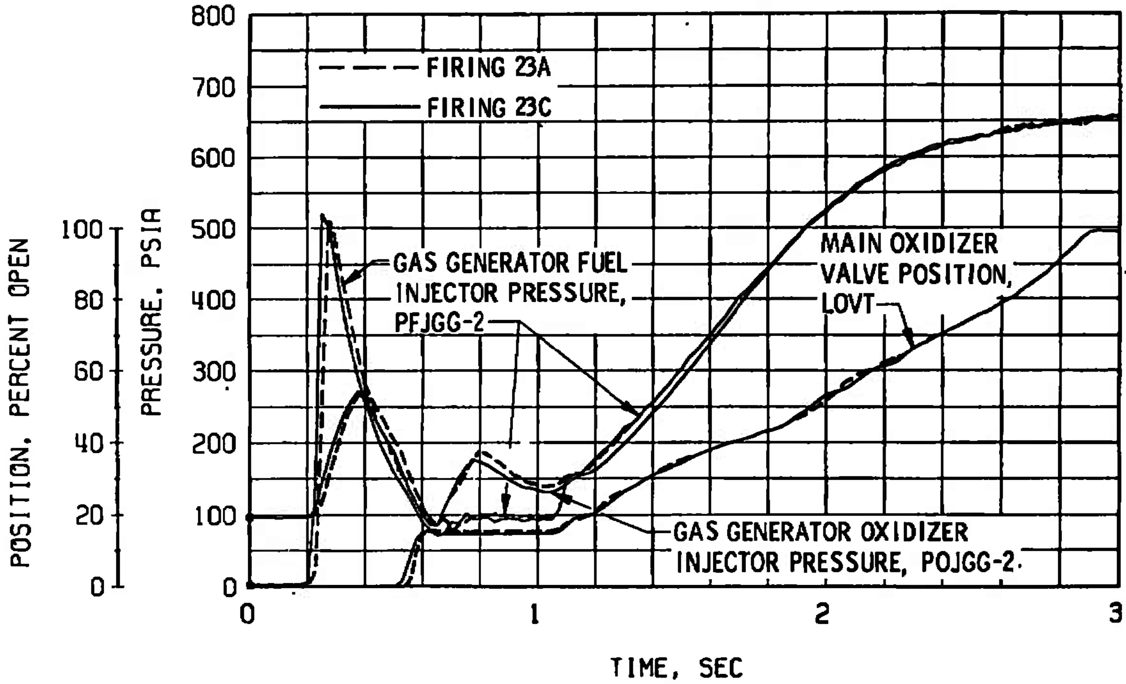


c. Thrust Chamber Fuel System, Shutdown

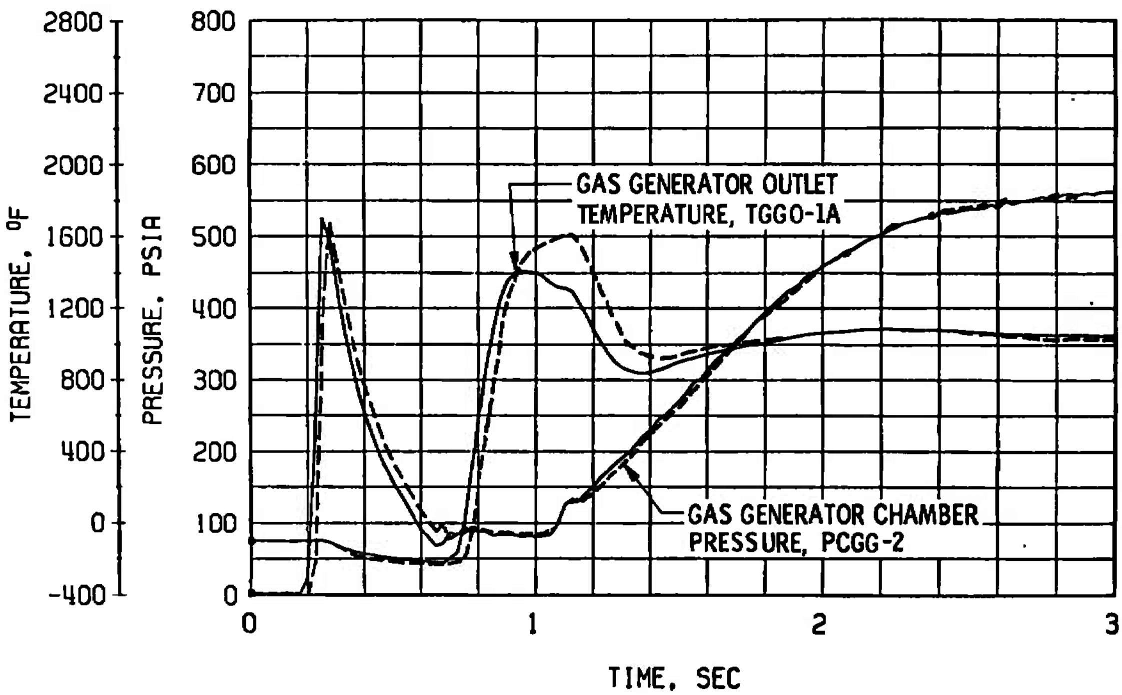


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 18 Continued

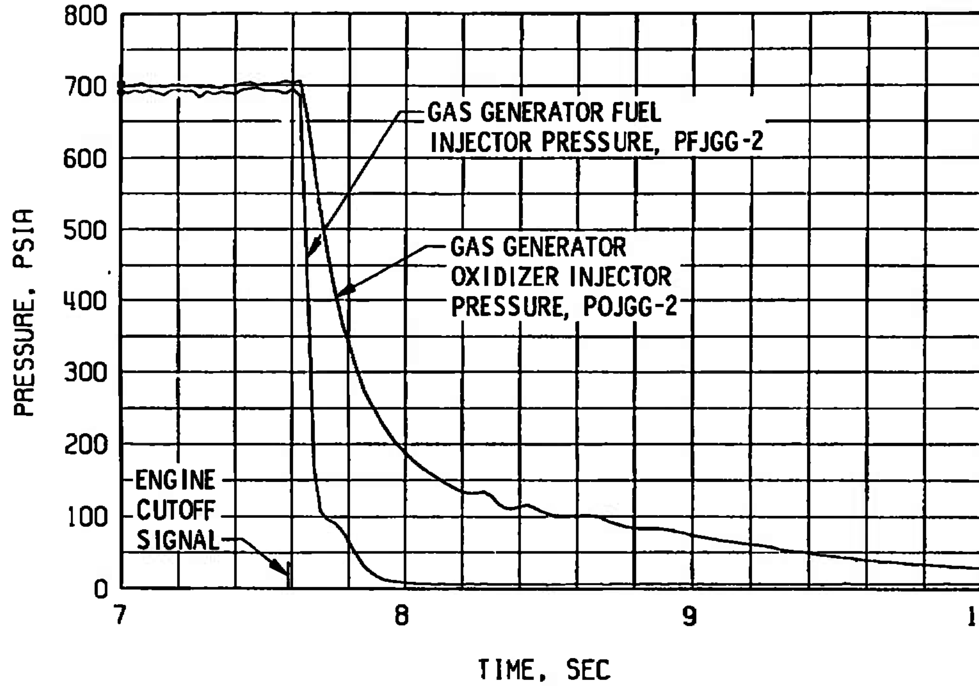


e. Gas Generator Injector Pressure and Main Oxidizer Valve Position, Start, Comparison of Firings 23A and 23C

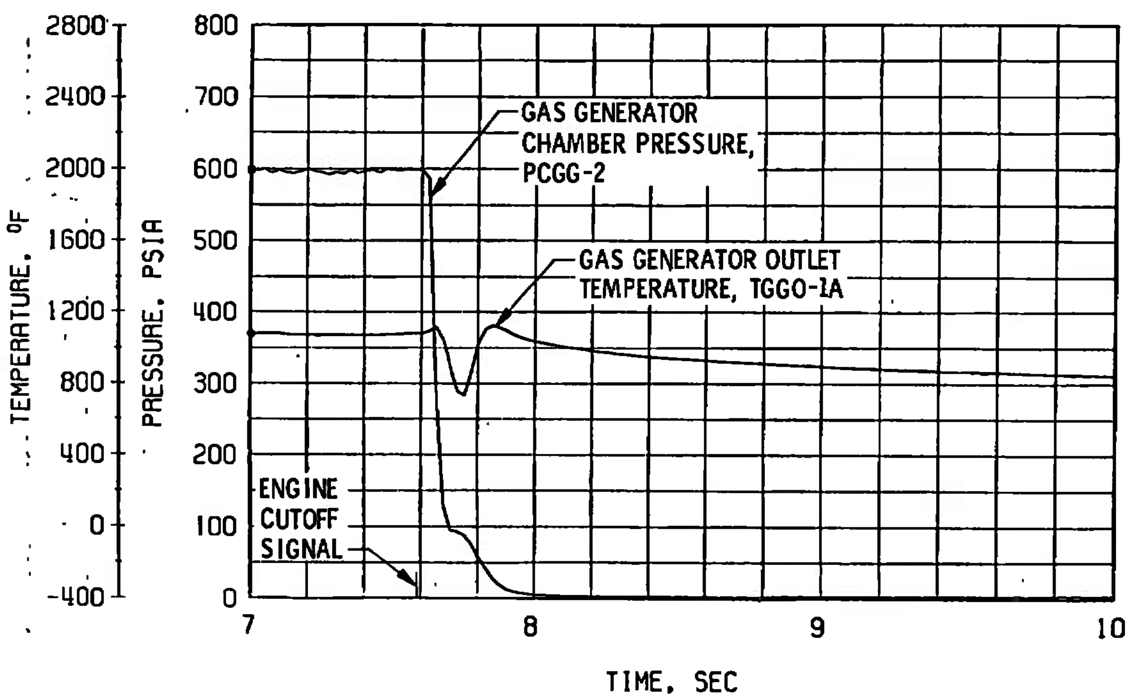


f. Gas Generator Chamber Pressure and Temperature, Start, Comparison of Firings 23A and 23C

Fig. 18 Continued



g. Gas Generator Injector Pressure, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 18 Concluded

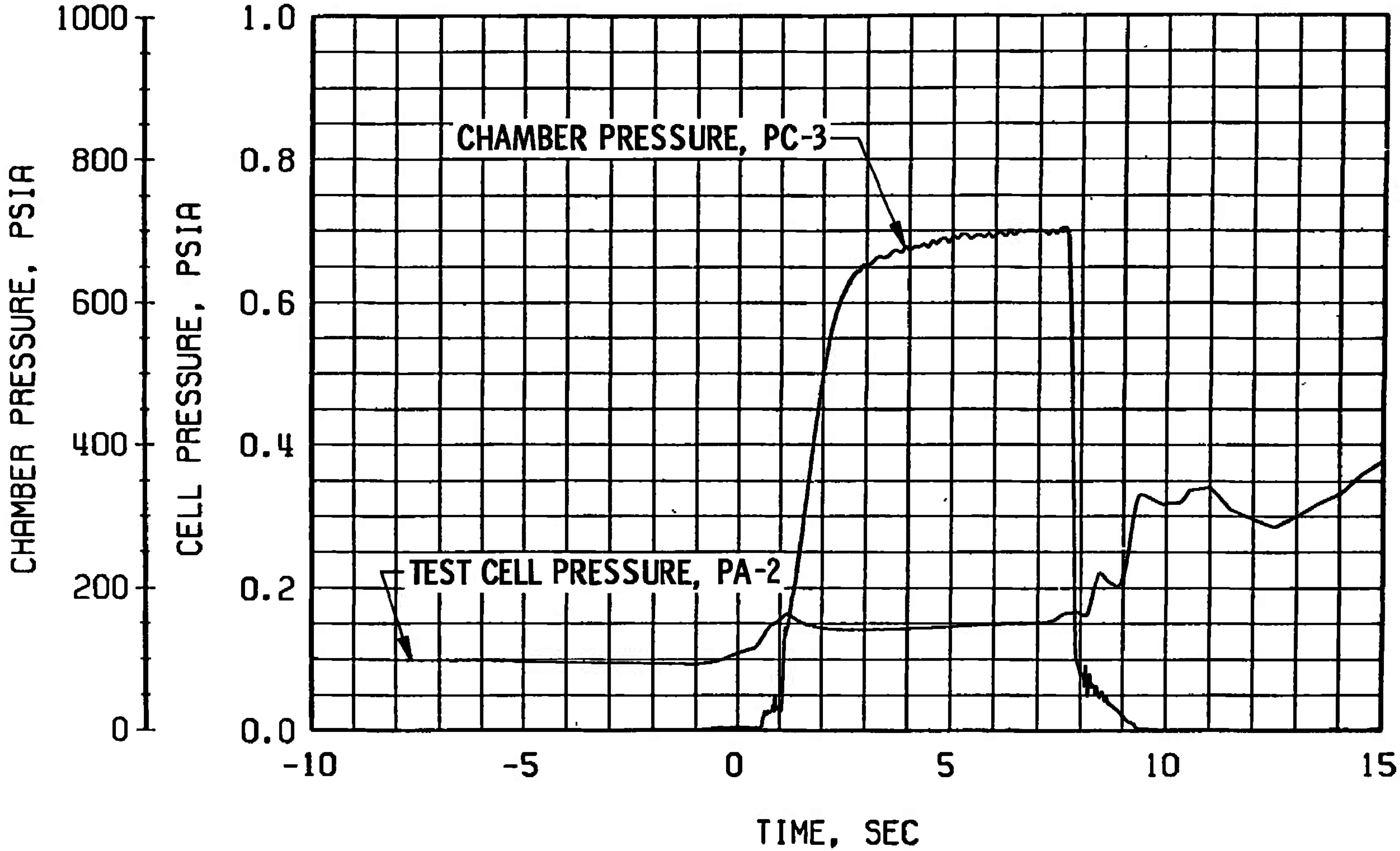
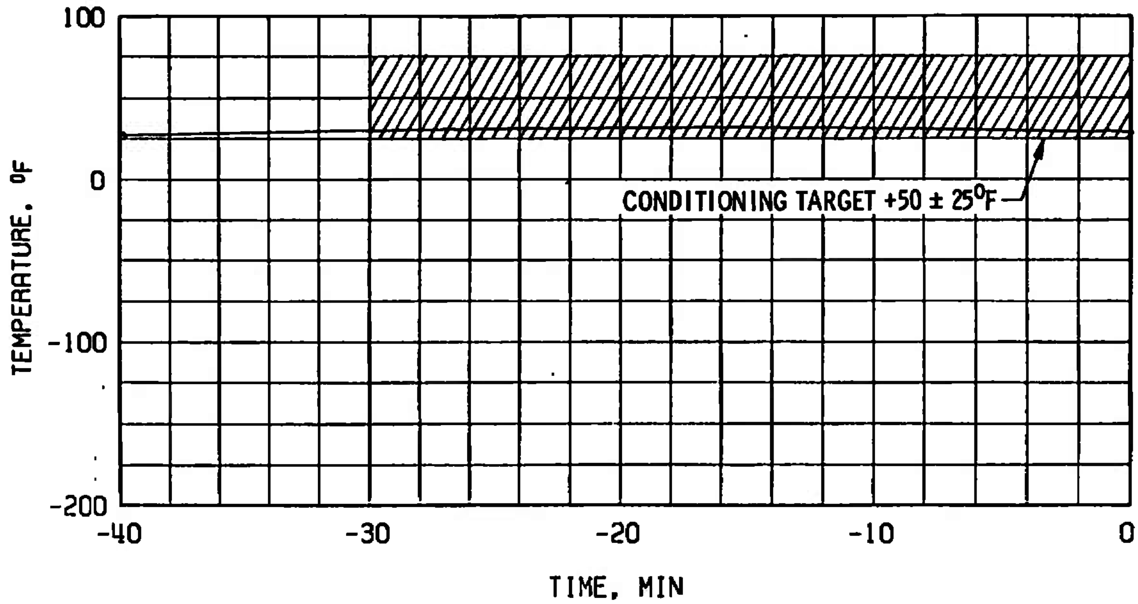
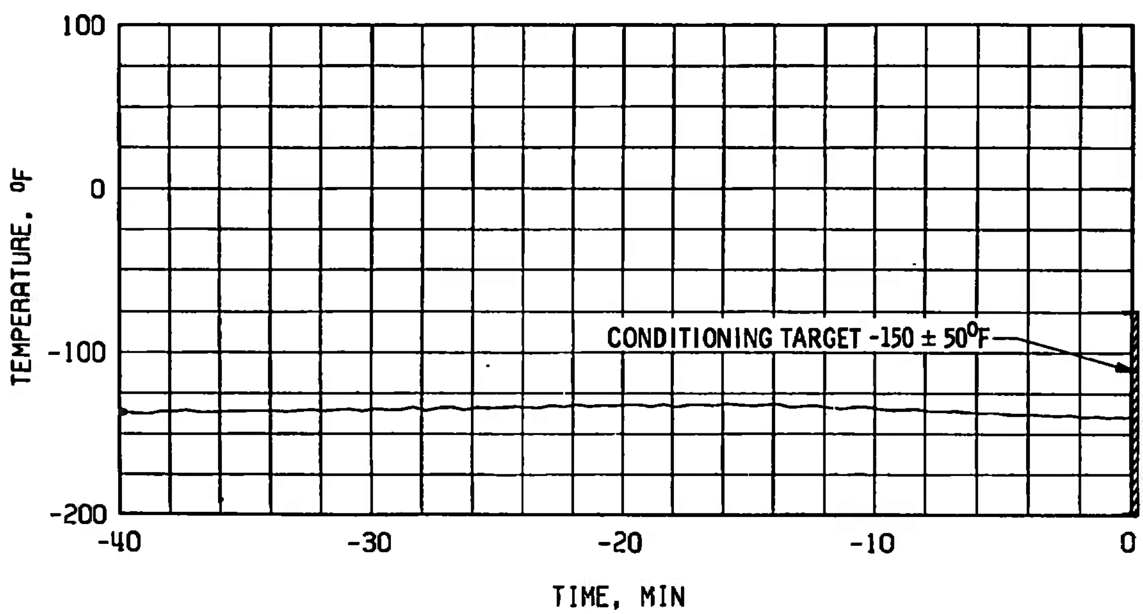


Fig. 19 Engine Ambient and Combustion Chamber Pressure, Firing 23C

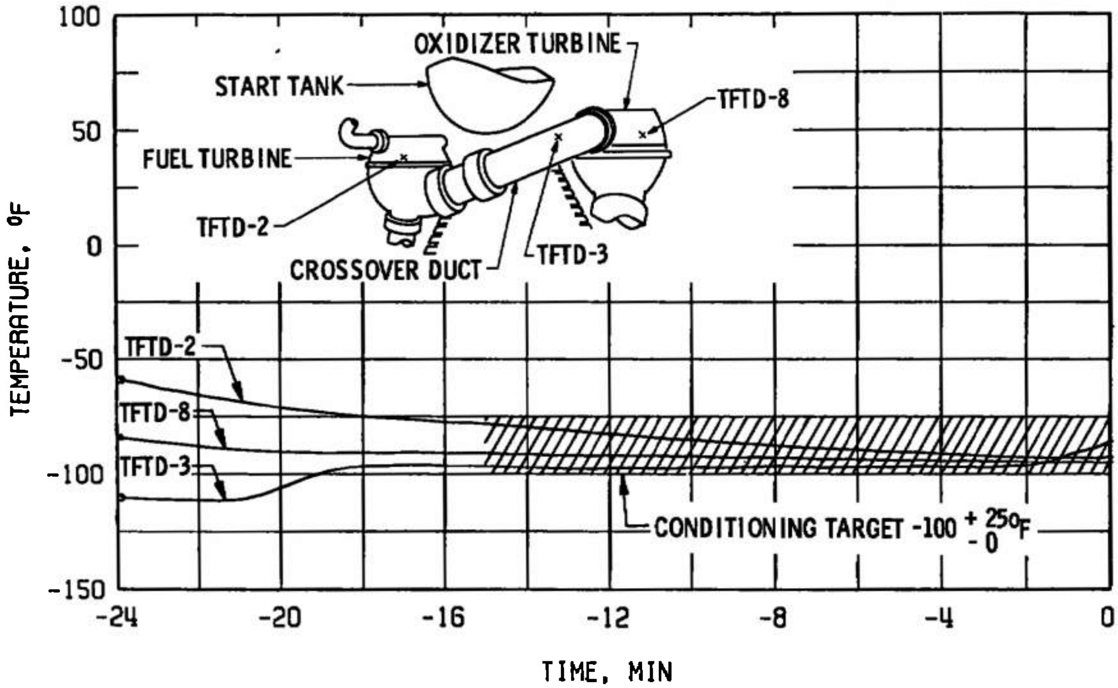


a. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

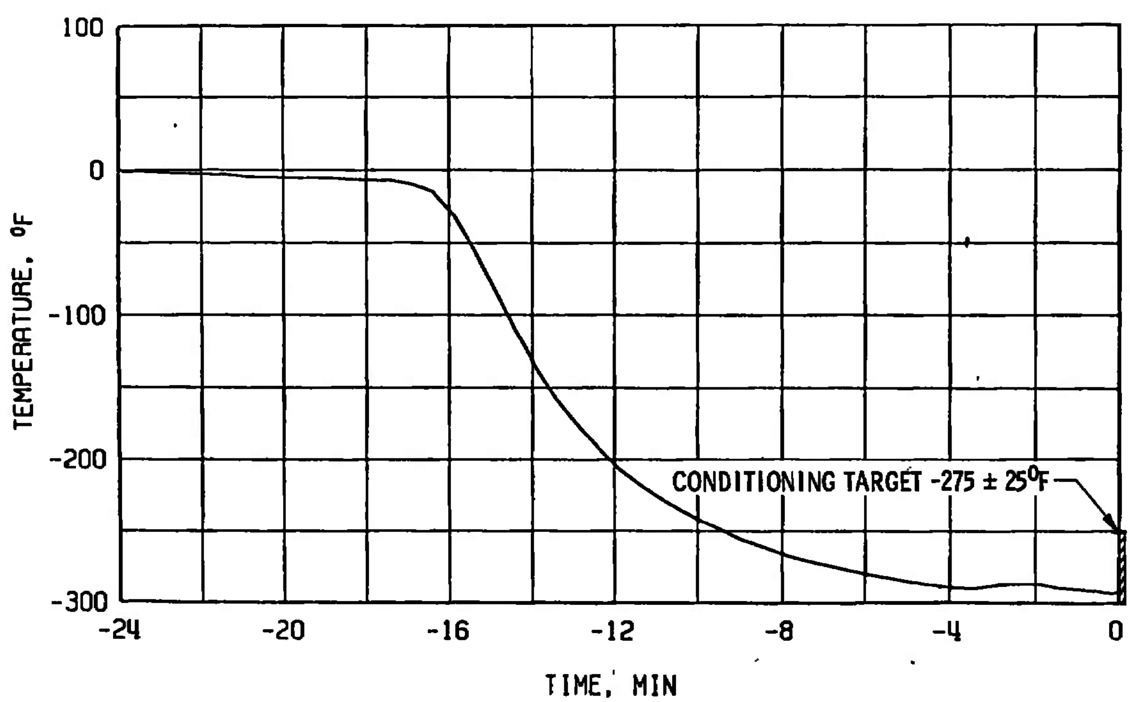


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 20 Thermal Conditioning History of Engine Components, Firing 23C



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 20 Concluded

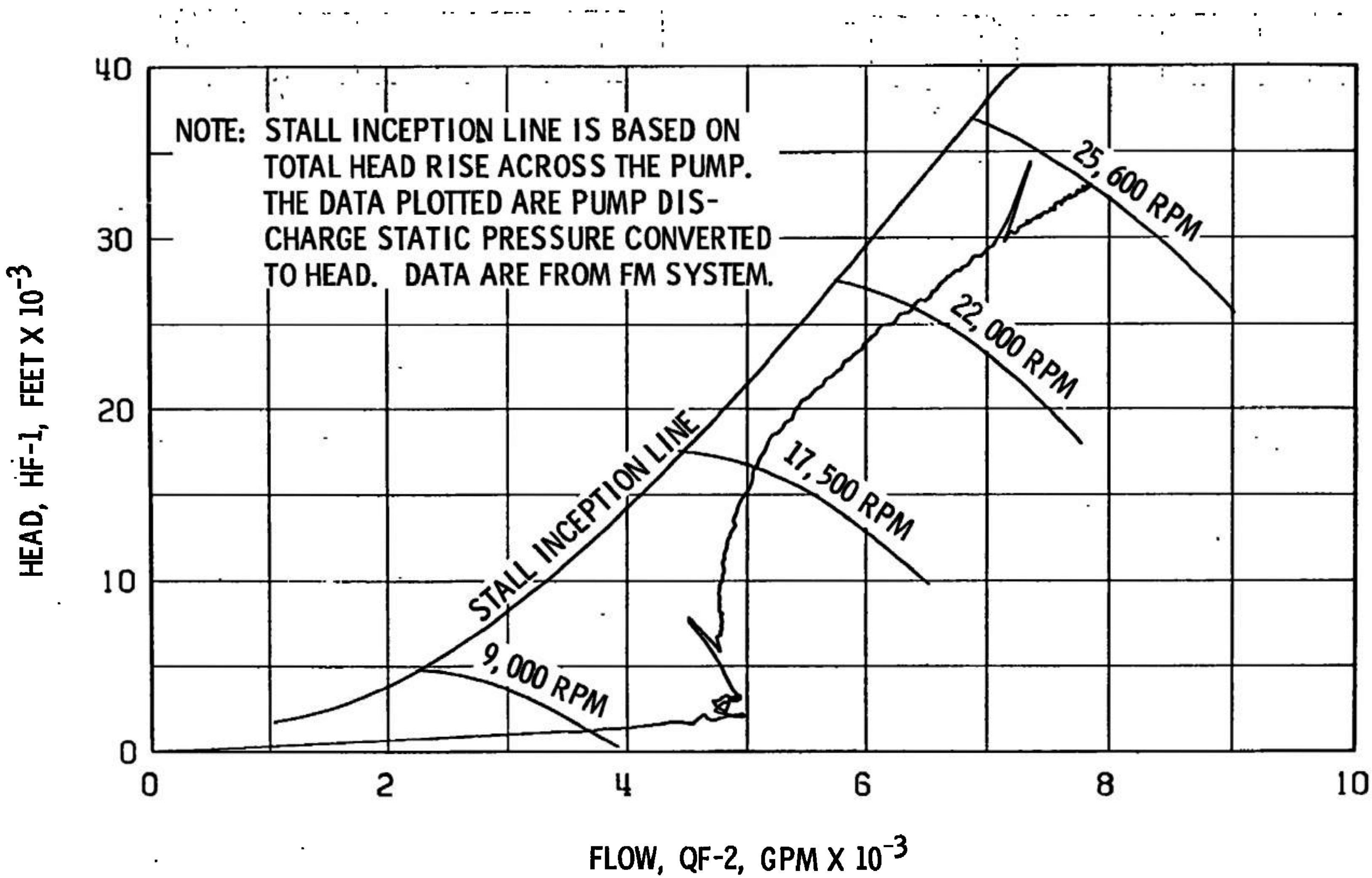
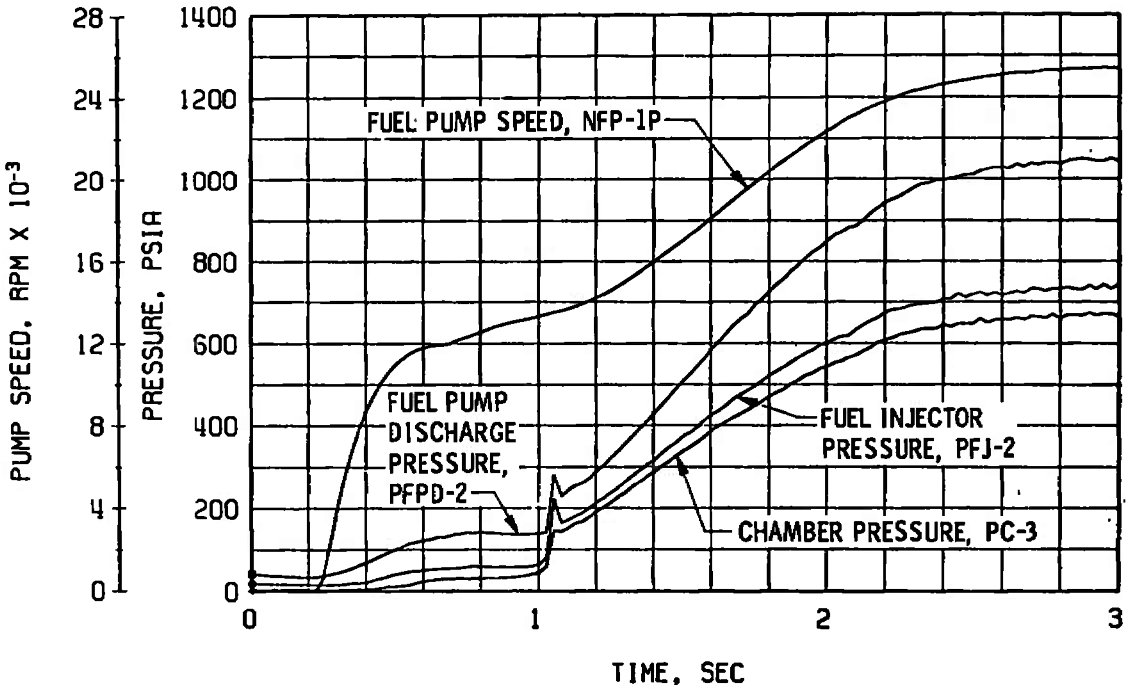
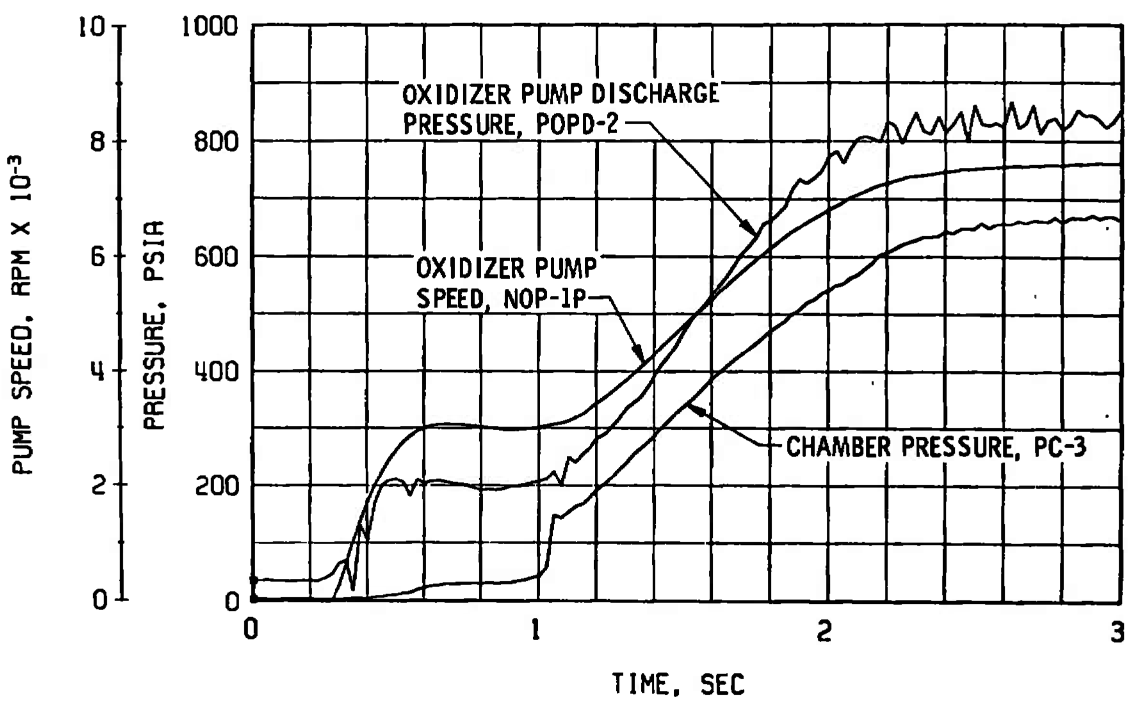


Fig. 21 Fuel Pump Start Transient Performance, Firing 23C

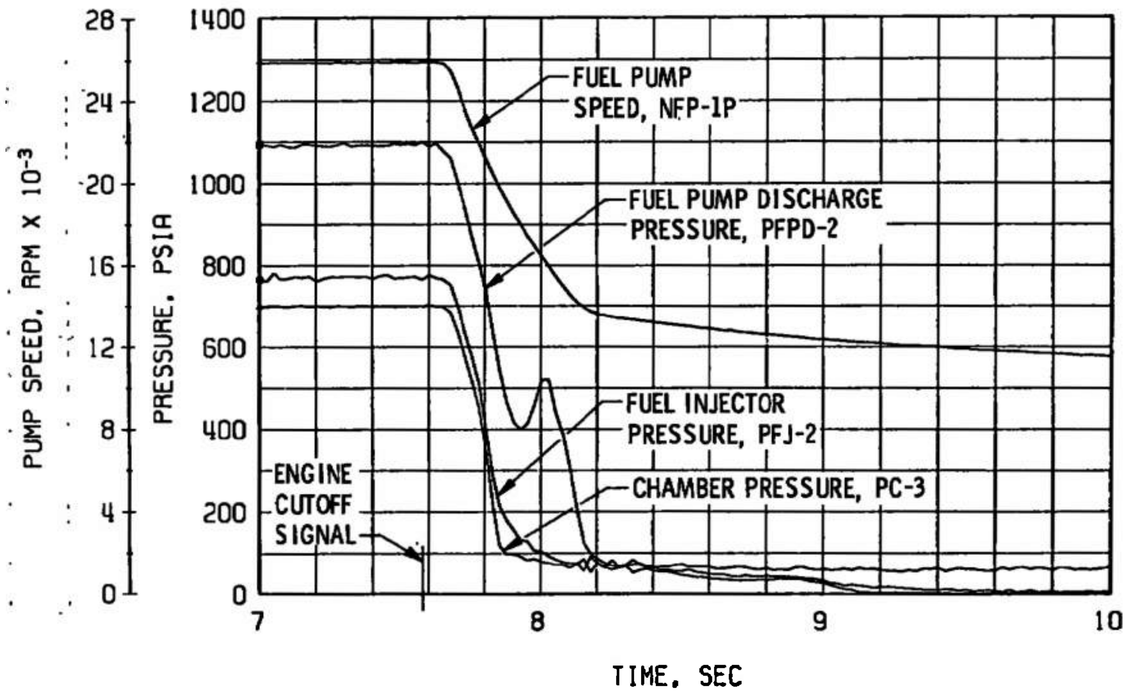


a. Thrust Chamber Fuel System, Start

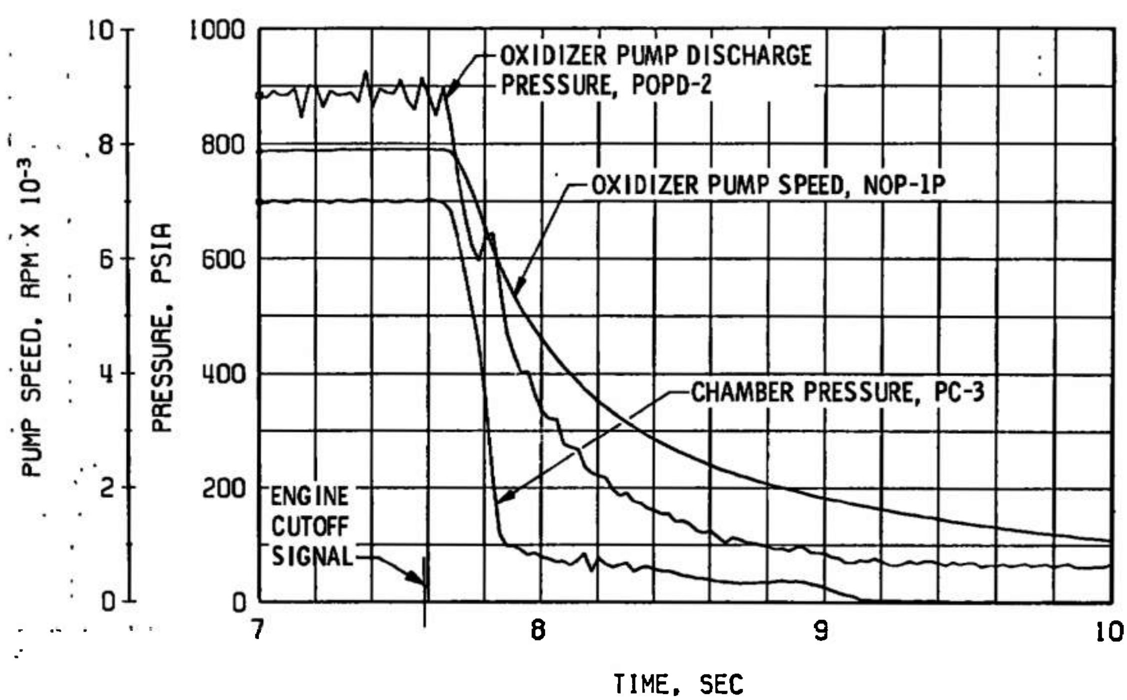


b. Thrust Chamber Oxidizer System, Start

Fig. 22 Engine Transient Operation, Firing 23D

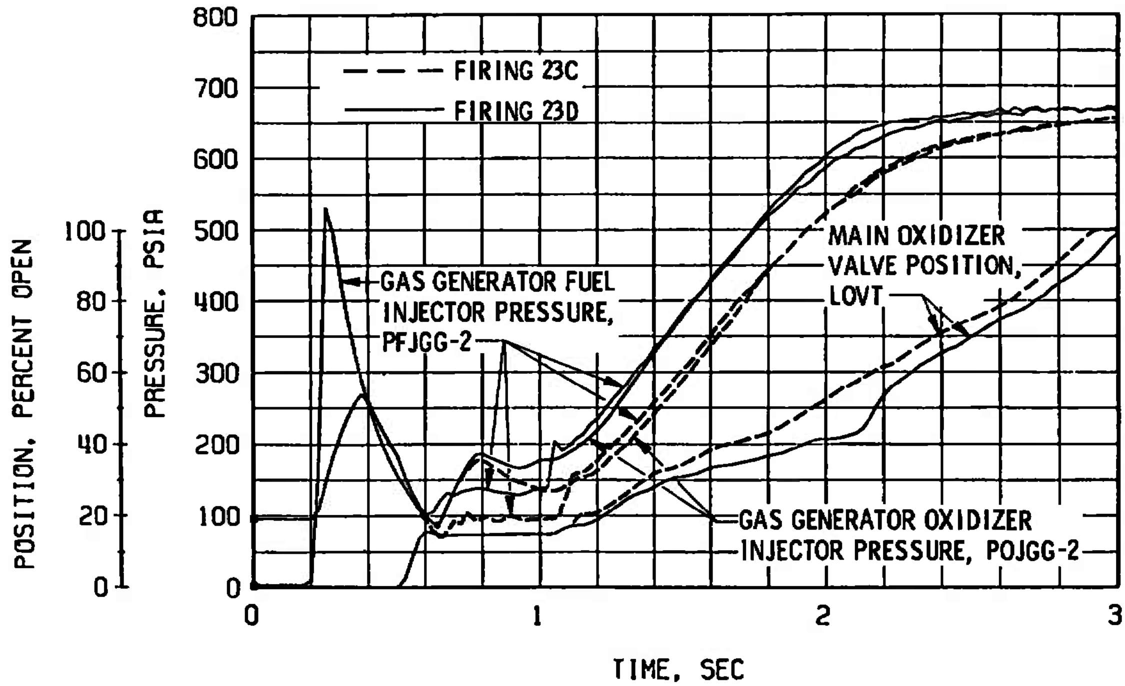


c. Thrust Chamber Fuel System, Shutdown

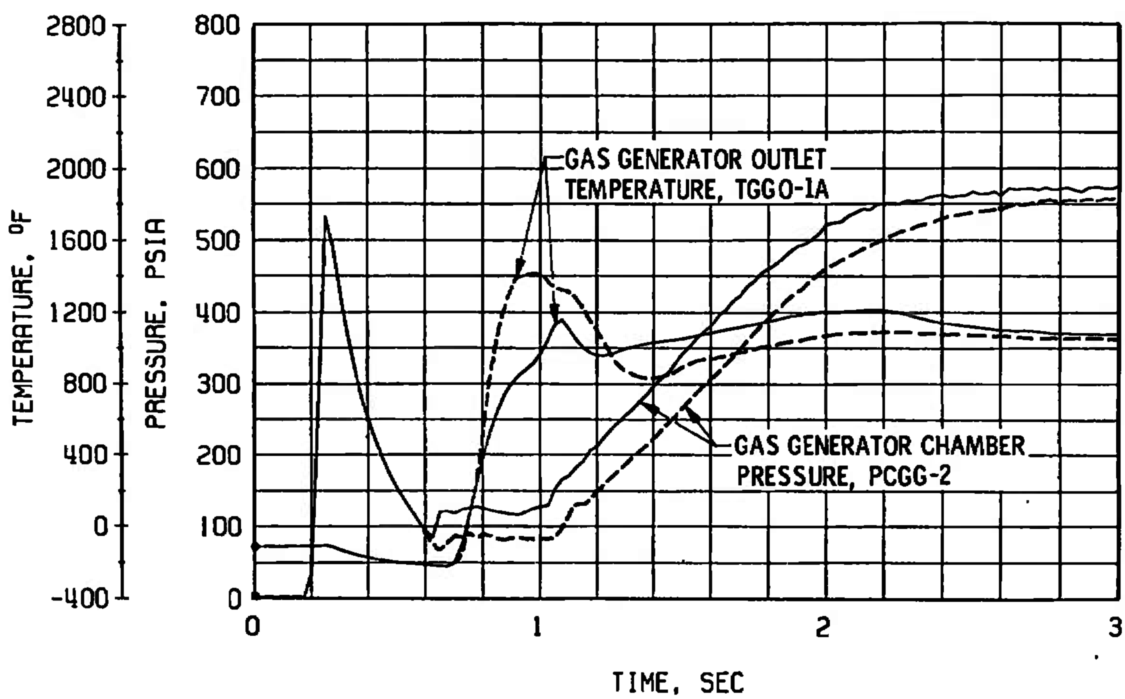


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 22 Continued

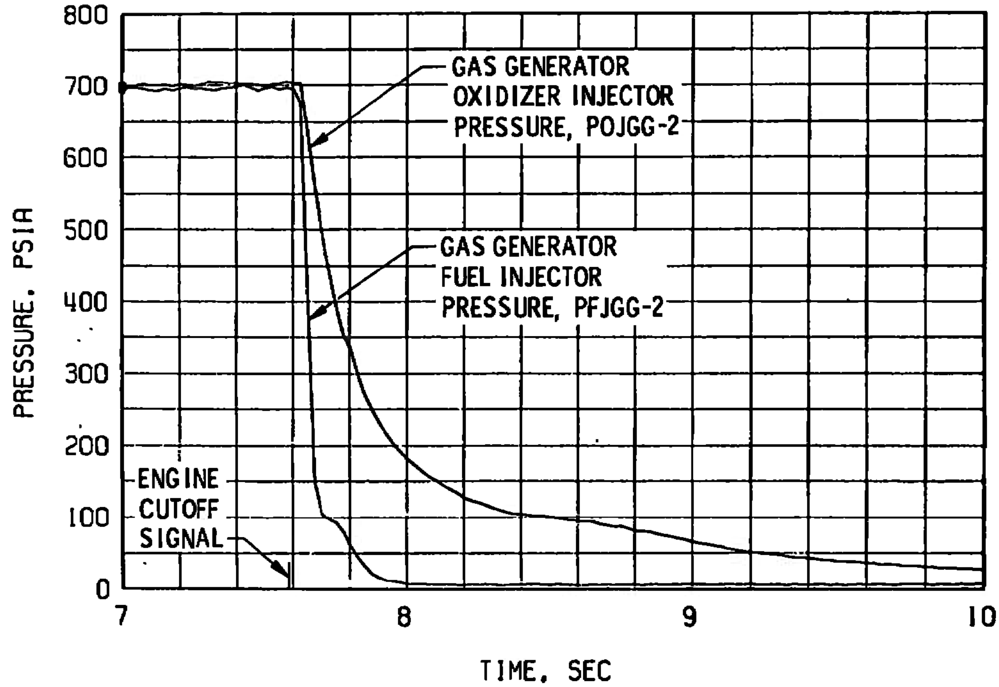


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start, Comparison of Firings 23C and 23D

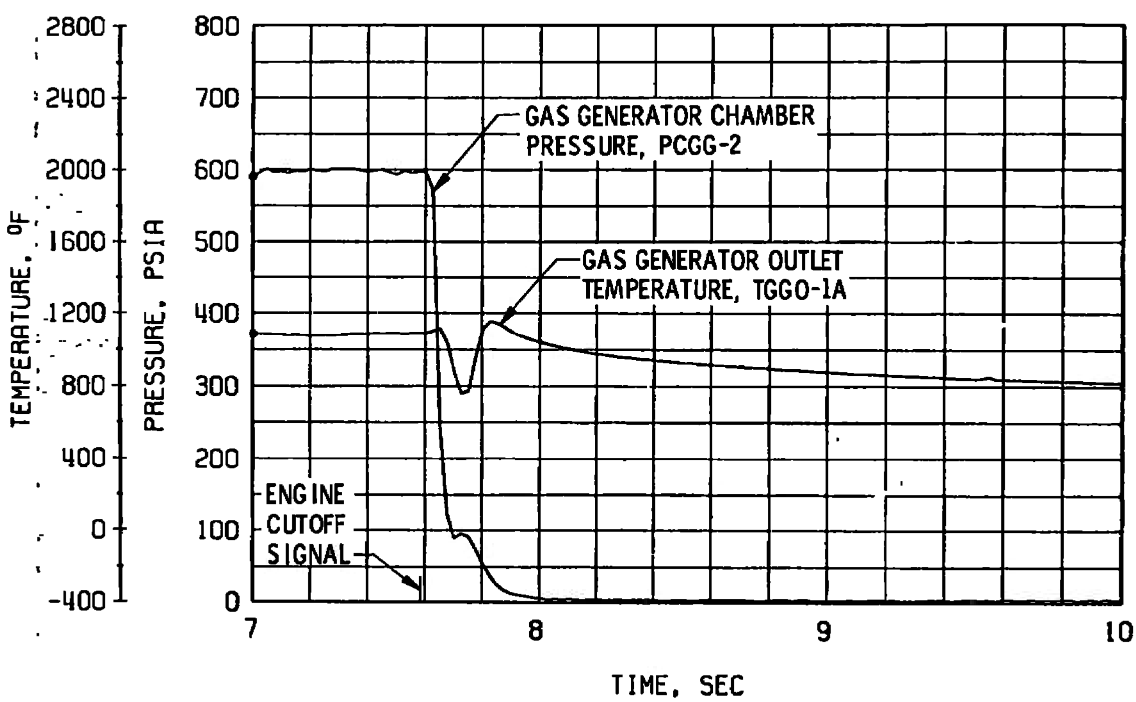


f. Gas Generator Chamber Pressure and Temperature, Start, Comparison of Firings 23C and 23D

Fig. 22 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 22 Concluded

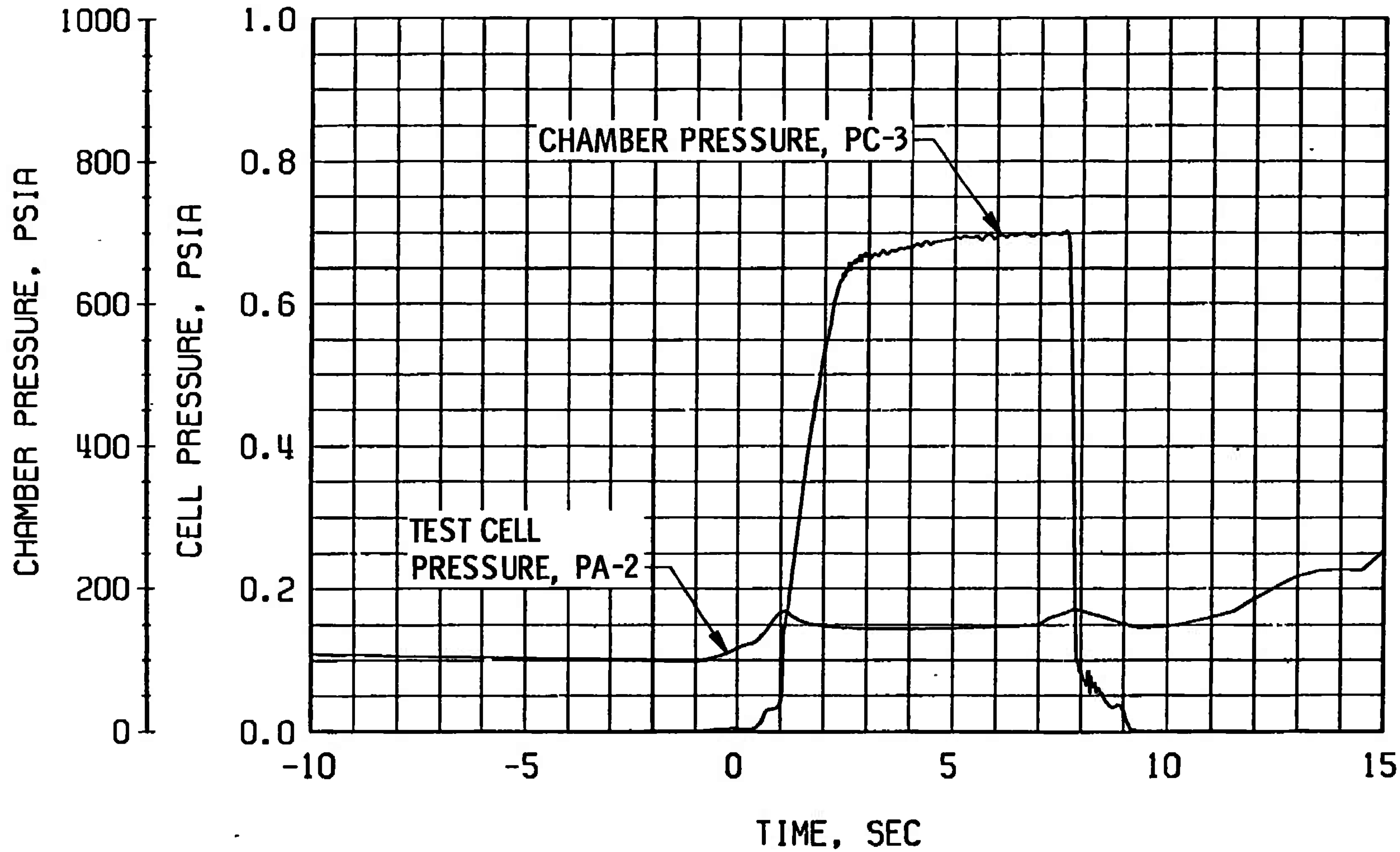
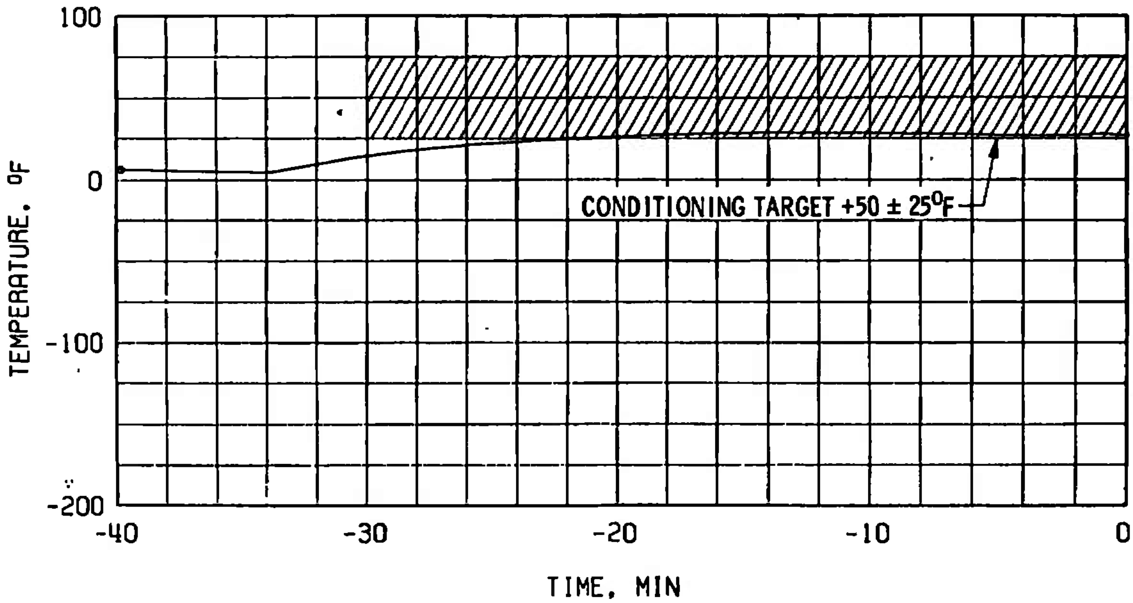
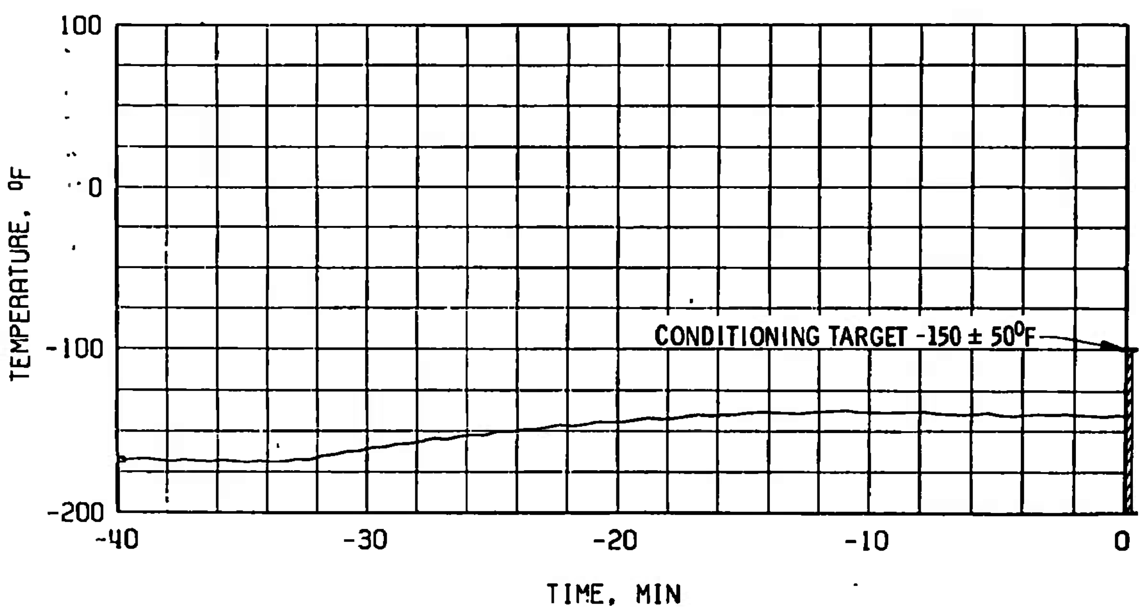


Fig. 23 Engine Ambient and Combustion Chamber Pressure, Firing 23D

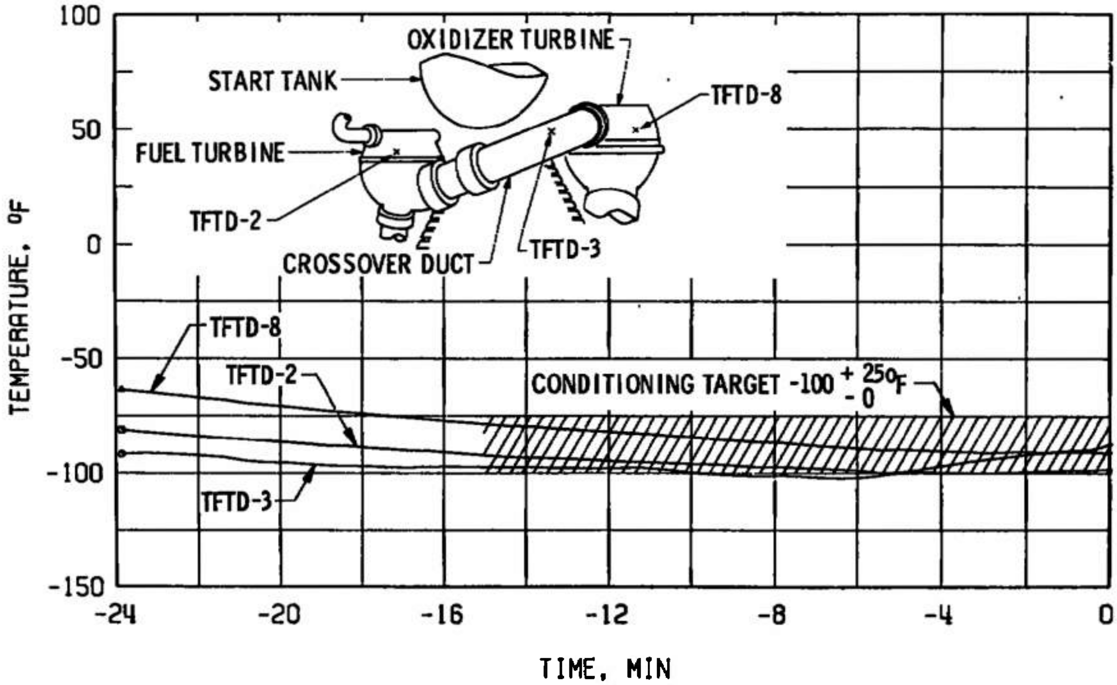


a. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

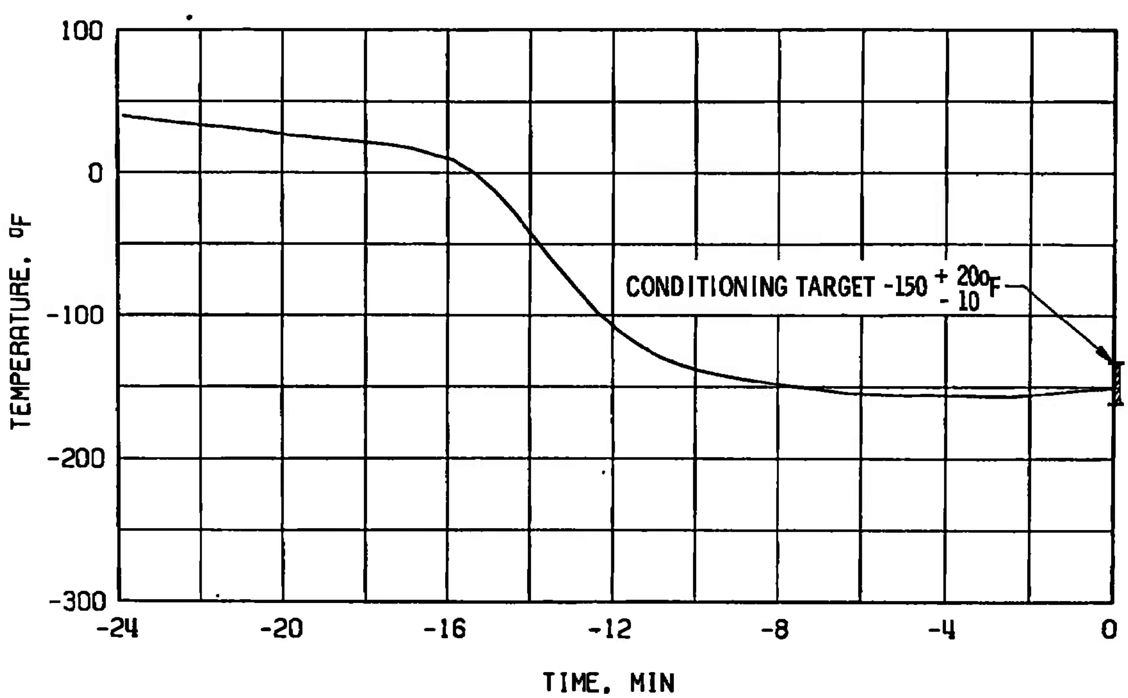


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 24 Thermal Conditioning History of Engine Components, Firing 23D



c. Crossover Duct, TFTD



d. Thrust Chamber Throat TTC-1P

Fig. 24 Concluded

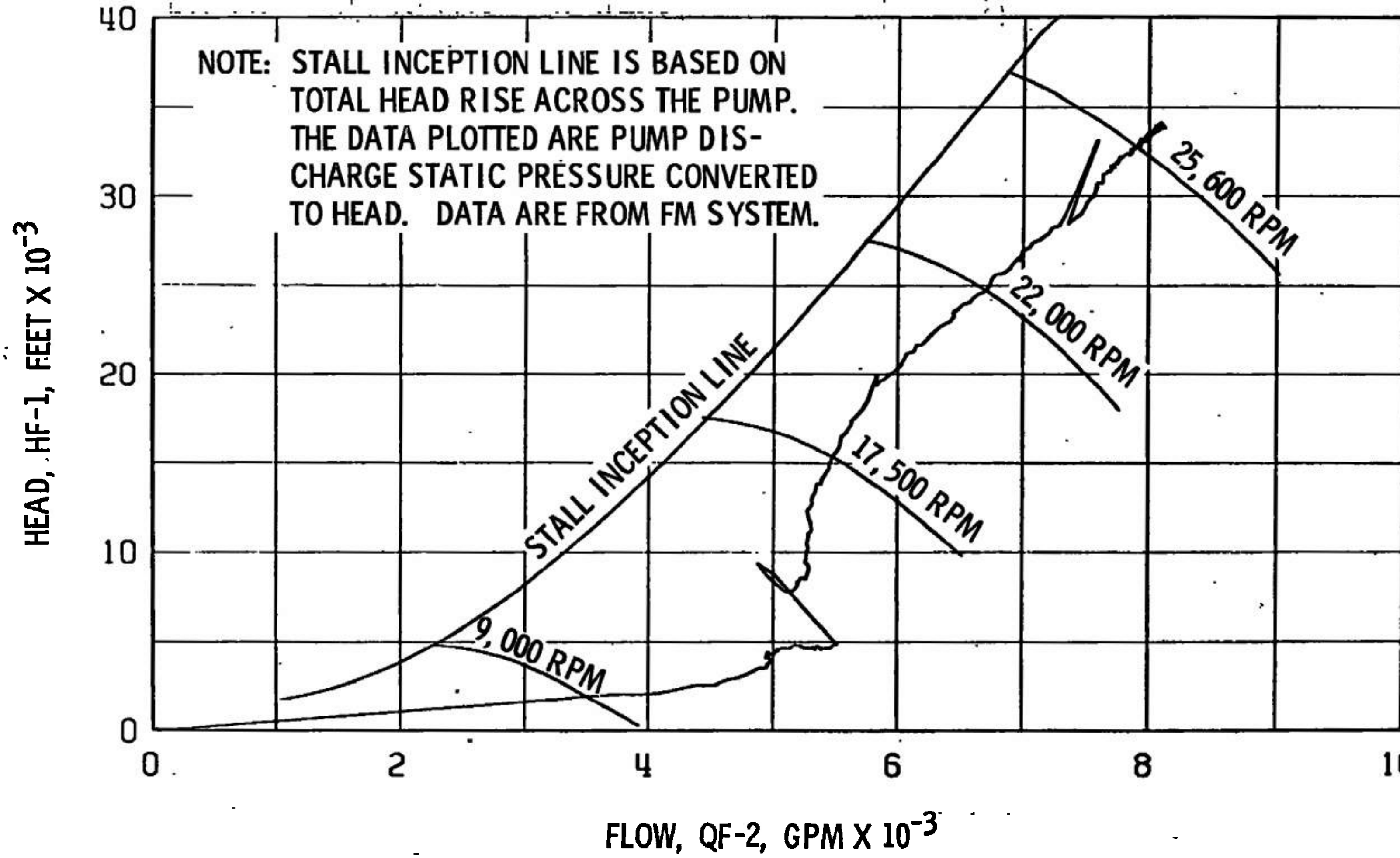


Fig. 25 Fuel Pump Start Transient Performance, Firing 23D

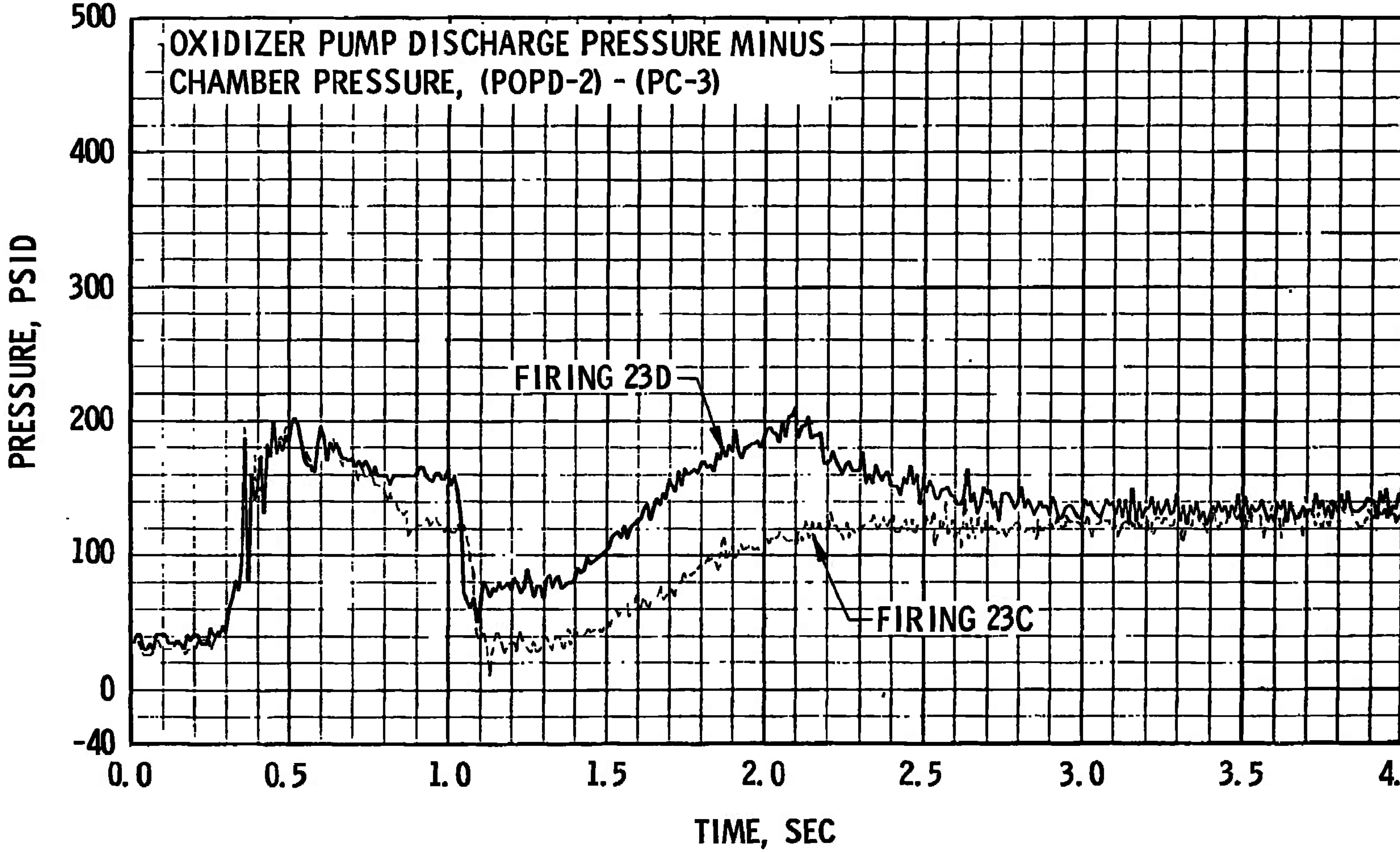
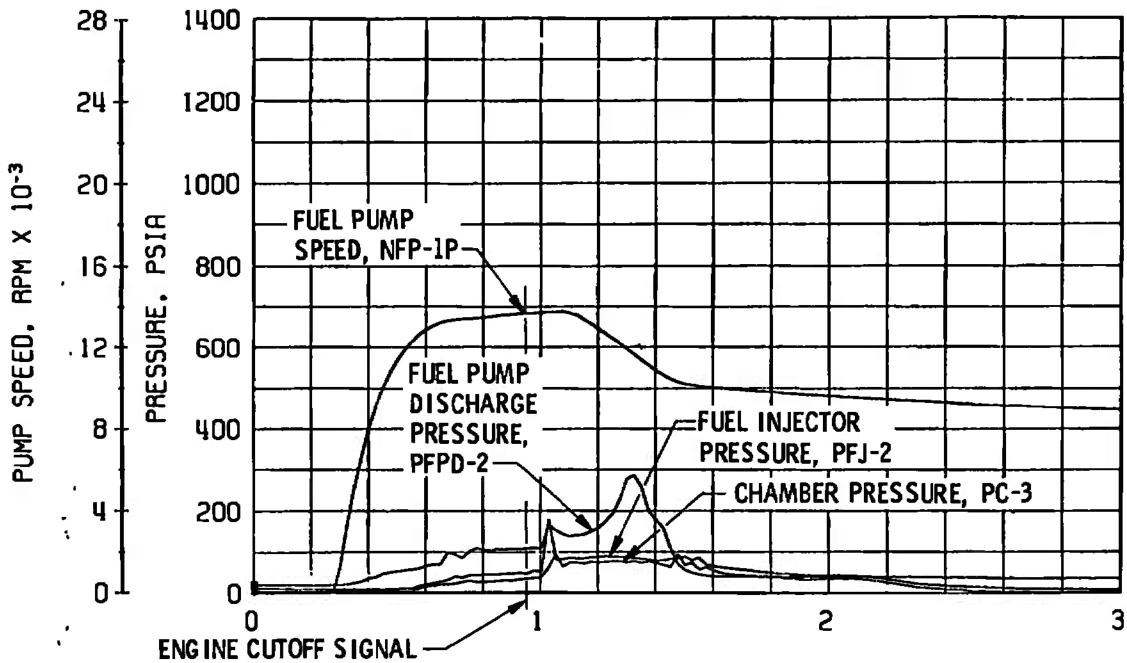
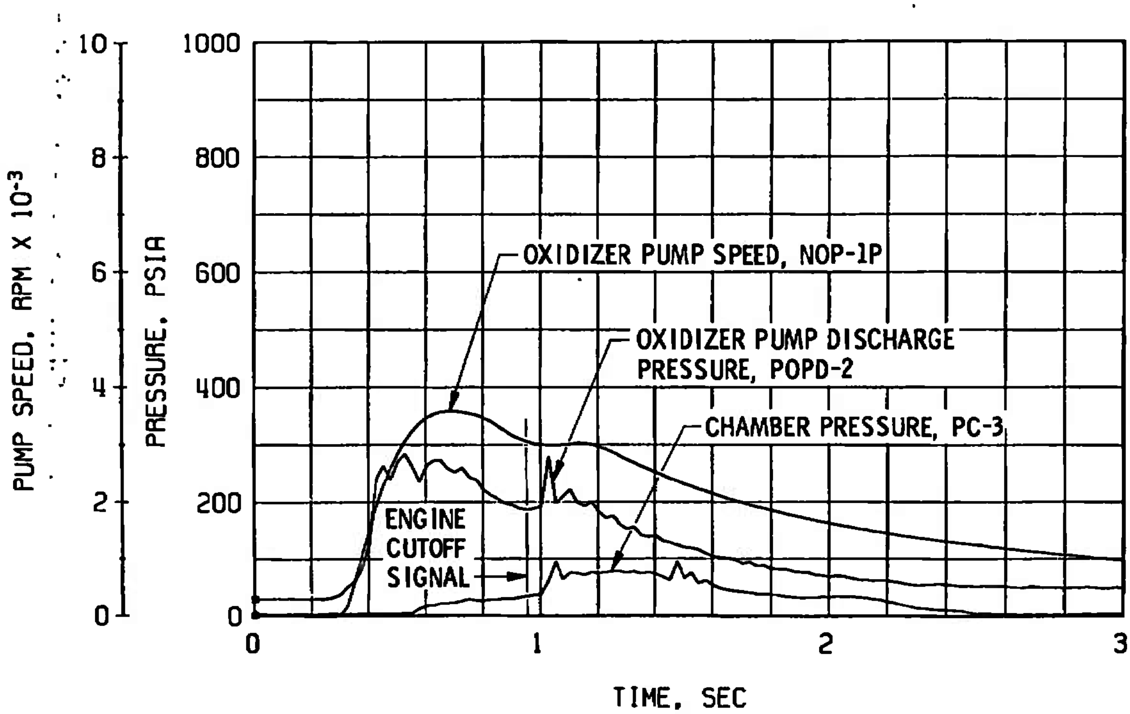


Fig. 26 Differential Pressure across Main Oxidizer Valve, Comparison of Firings 23C and 23D

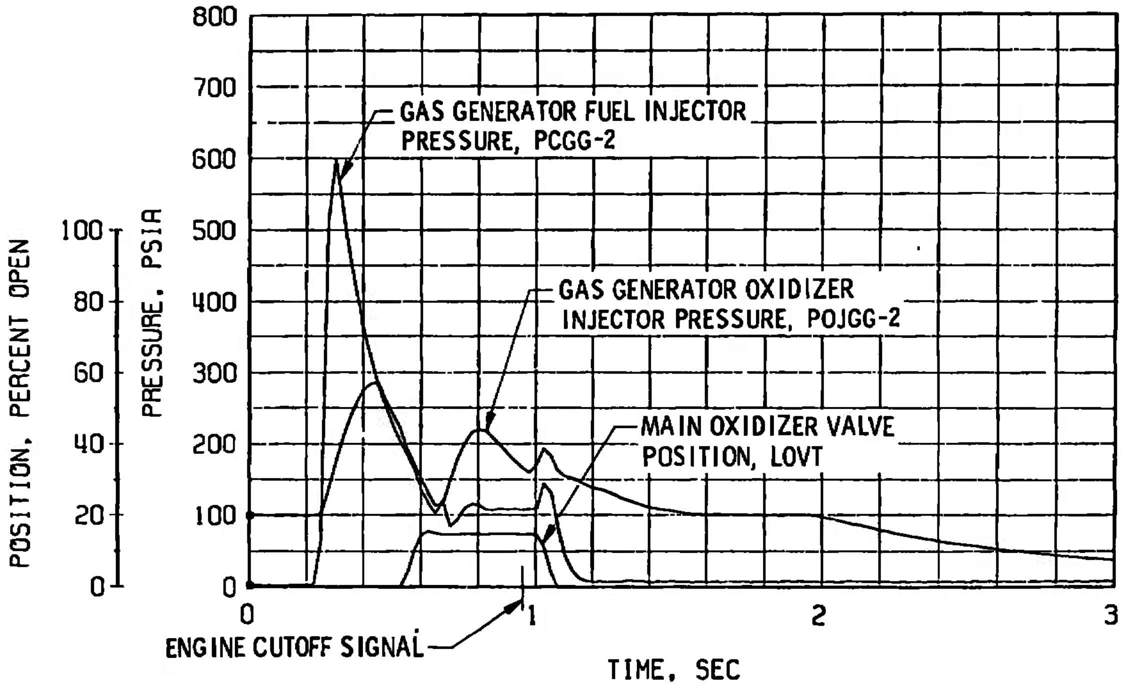


a. Thrust Chamber Fuel System, Start and Shutdown

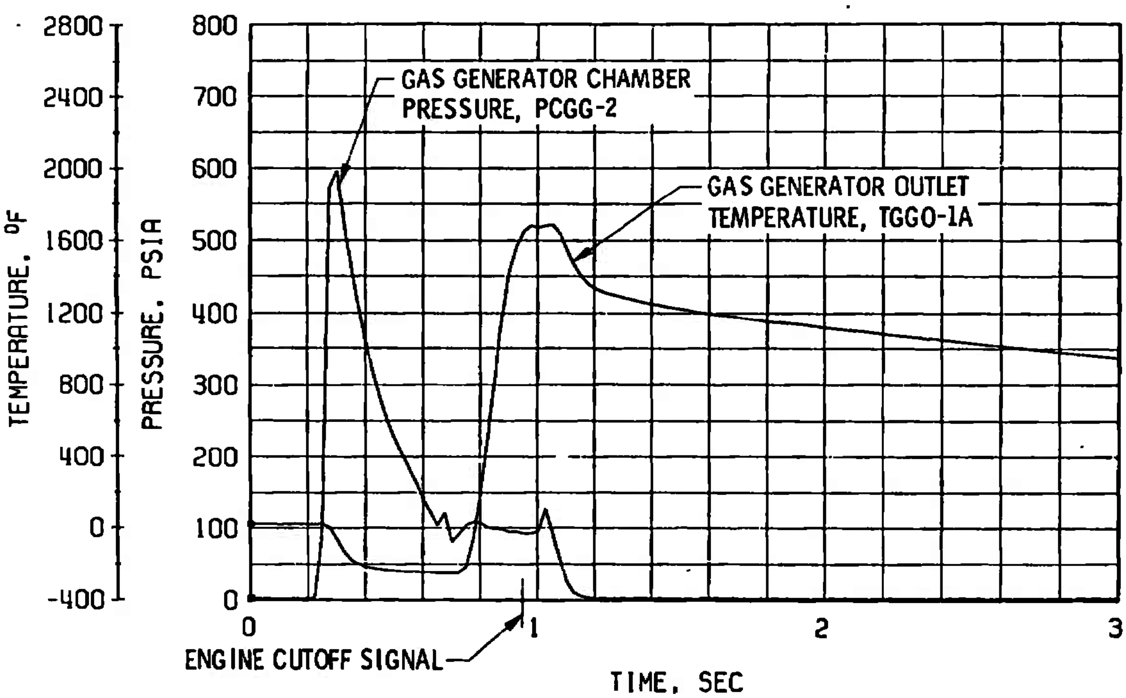


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 27 Engine Transient Operation, Firing 23E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 27 Concluded

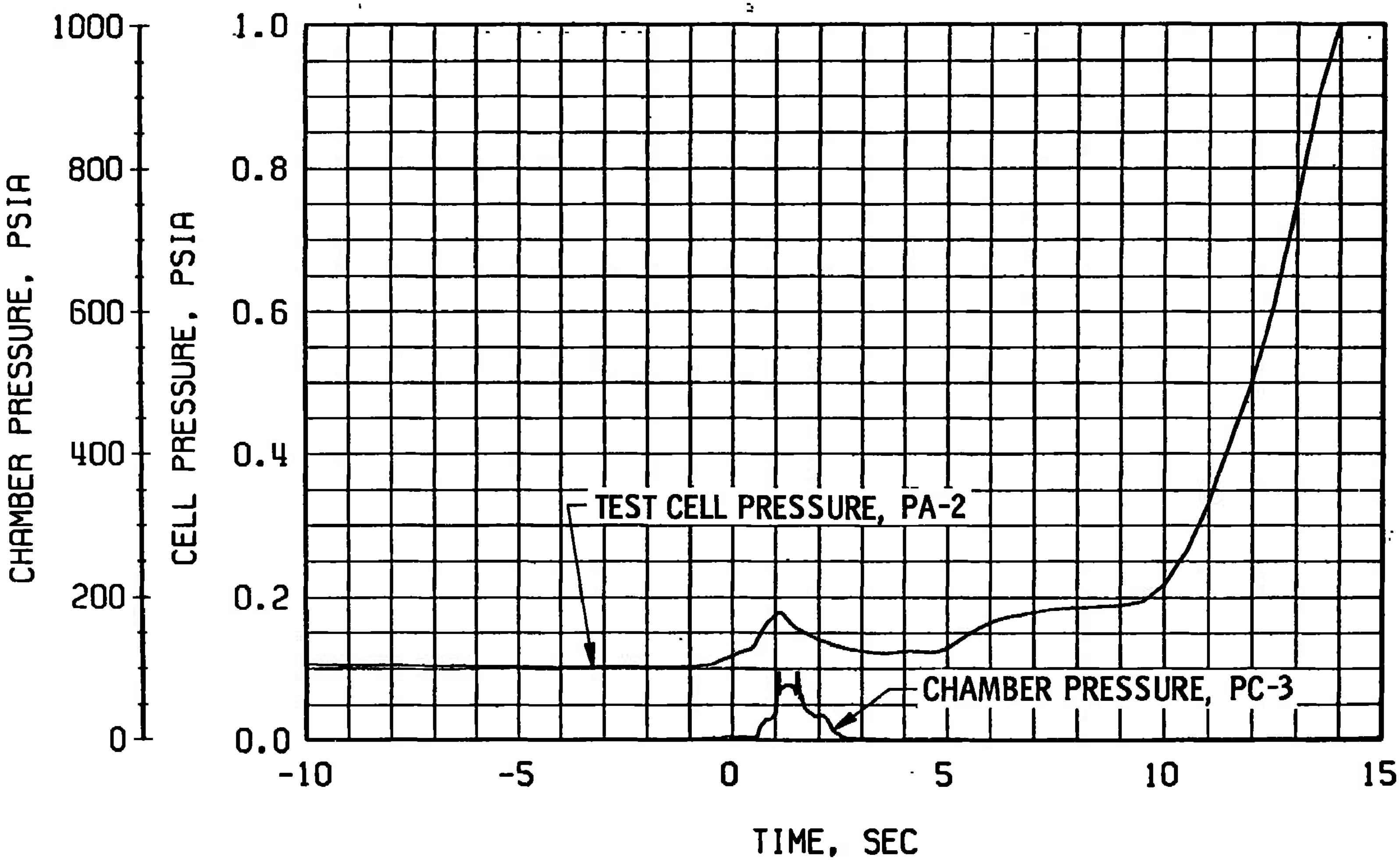
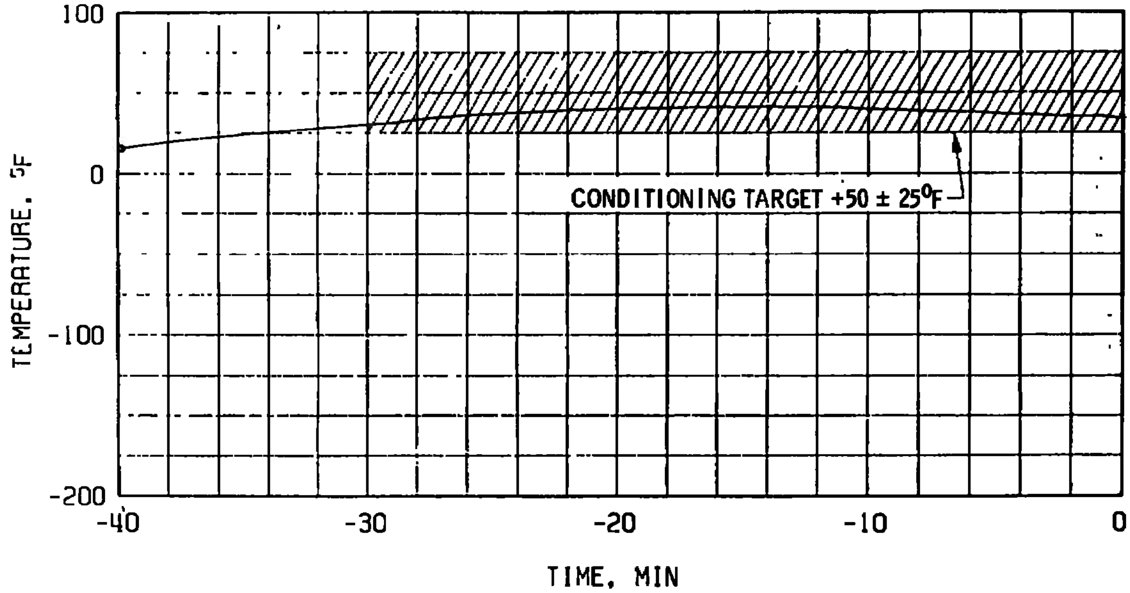
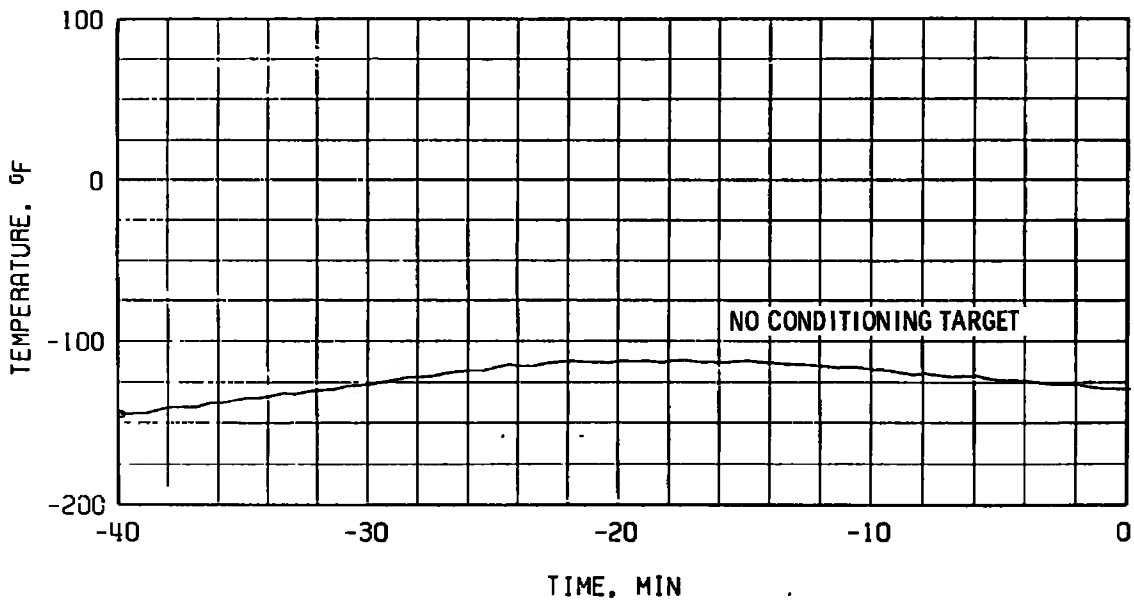


Fig. 28 Engine Ambient and Combustion Chamber Pressure, Firing 23E

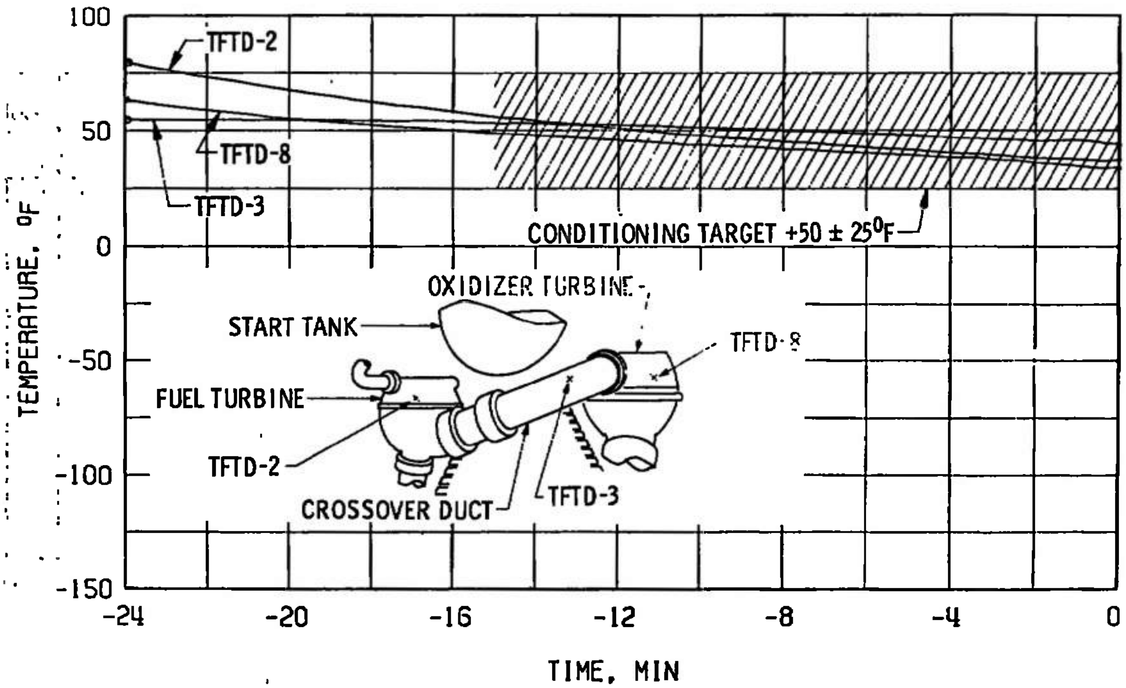


a. Start Tank Discharge Valve Opening Control Temperature, TSTDVOC

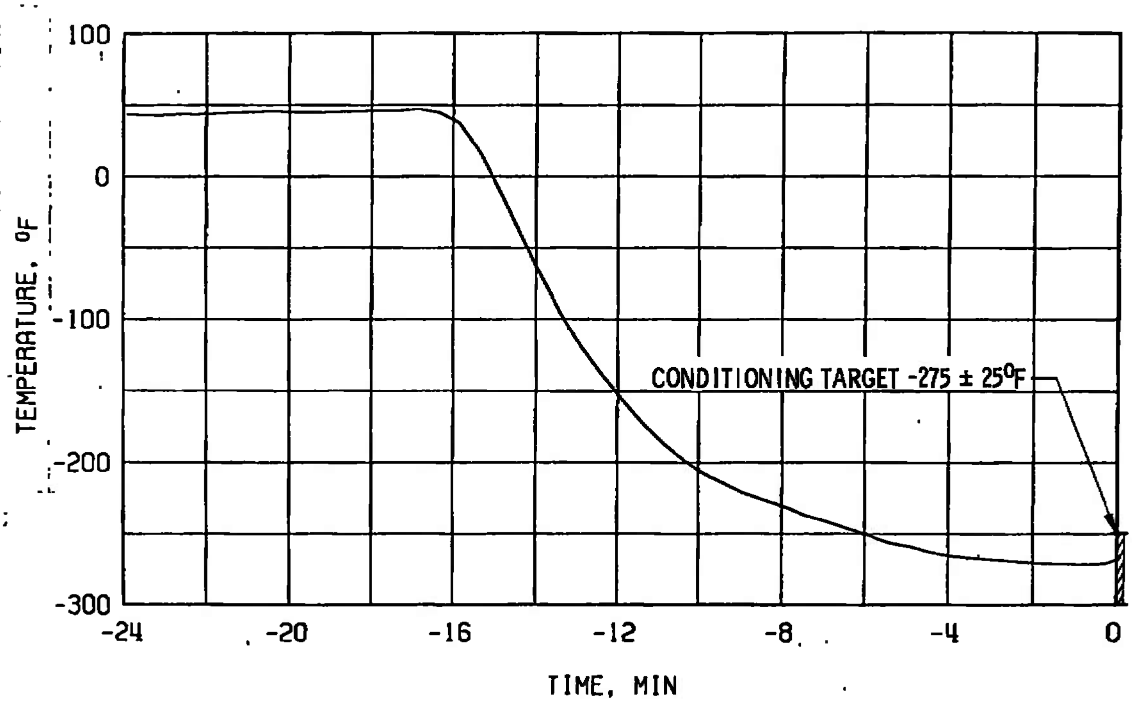


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 29 Thermal Conditioning History of Engine Components, Firing 23E



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 29 Concluded

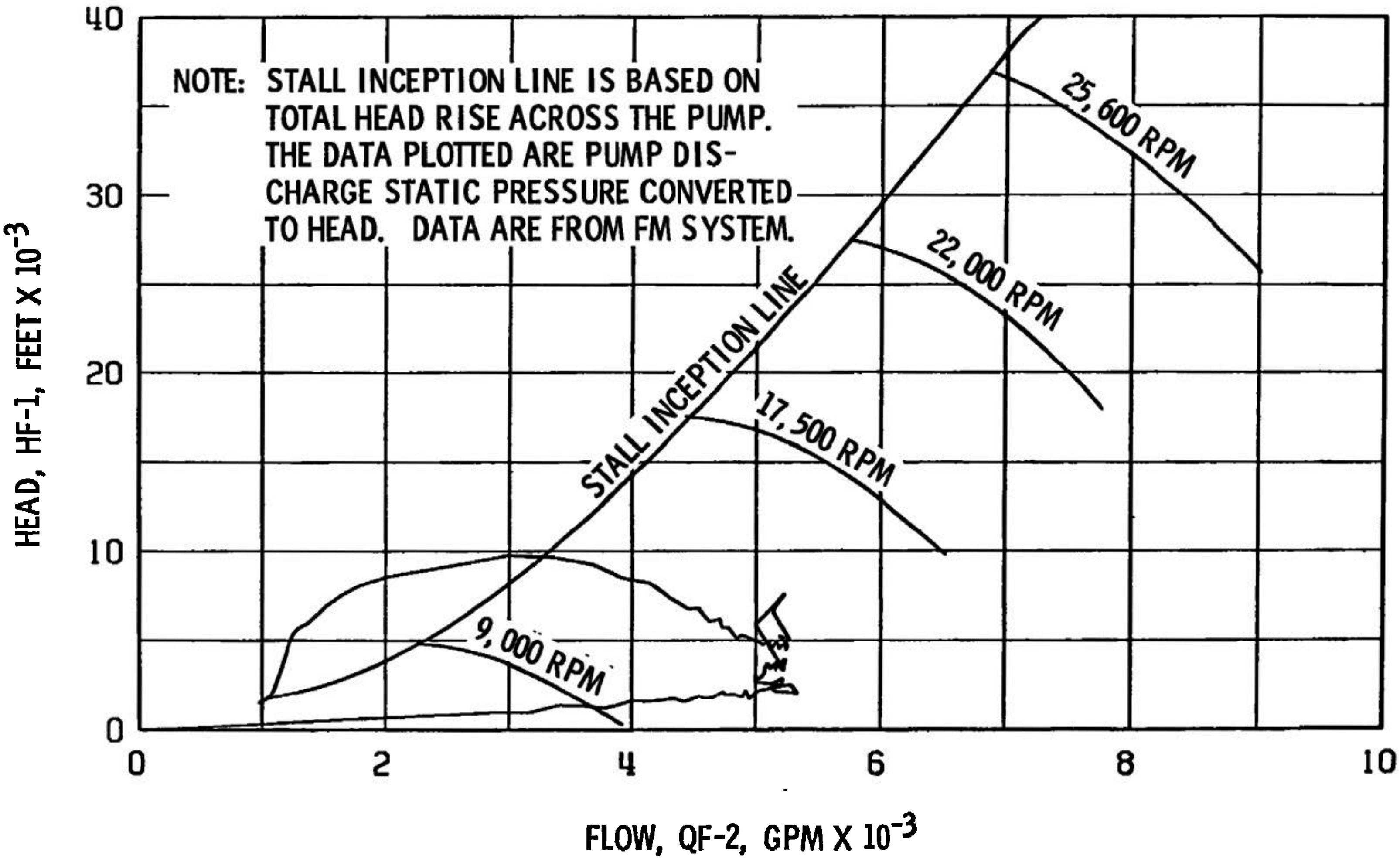


Fig. 30 Fuel Pump Start Transient Performance, Firing 23E

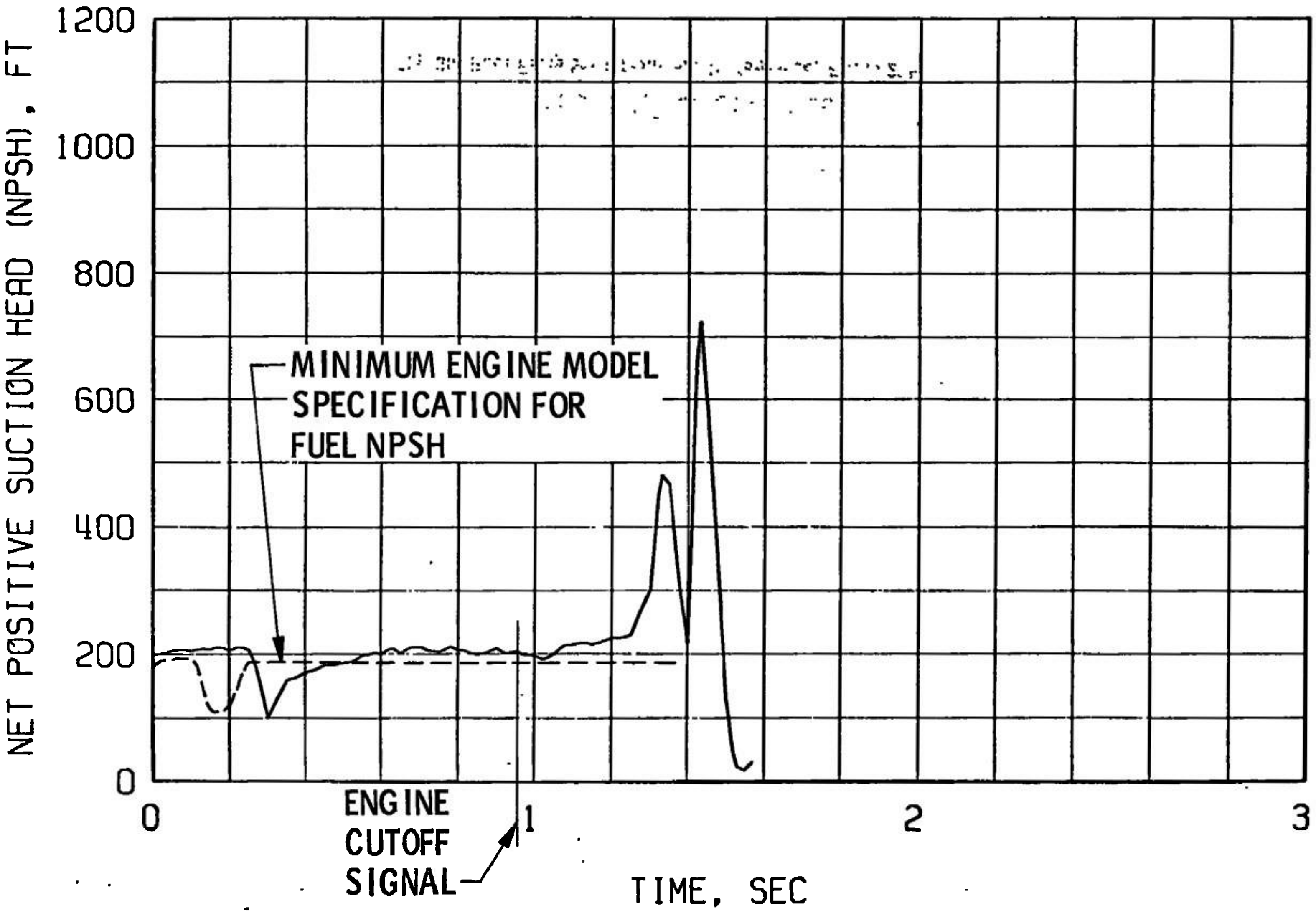


Fig. 31 Fuel Pump NPSH, Firing 23E

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4072755
Thrust Chamber Injector Assembly	208021-11	4071421
Fuel Turbopump Assembly	460160-31	4072328
Oxidizer Turbopump Assembly	458175-81	6645876
Start Tank	303439	0038
Augmented Spark Igniter	206280-81	4078806
Gas Generator Fuel Injector and Combustor	308360-11	4088543
Gas Generator Oxidizer Injector and Poppet Assembly	303323	4091740
Helium Regulator Assembly	556948	4072709
Electrical Control Package	502670-11	4078604
Primary Flight Instrumentation Package	703685	4077391
Auxiliary Flight Instrumentation Package	703680	4077313
Main Fuel Valve	409120	4062472
Main Oxidizer Valve	411031	4089563
Gas Generator Control Valve	309040	4074190
Start Tank Discharge Valve	306875	4081218
Oxidizer Turbine Bypass Valve	409930	4093026
Propellant Utilization Valve	251351-11	4068732
Main-Stage Control Valve	555767	8284307
Ignition Phase Control Valve	555767	8284305
Helium Control Valve	NA5-27273	340919
Start Tank Vent and Relief Valve	557818	4062234
Helium Tank Vent Valve	NA5-27273	340918
Fuel Bleed Valve	309034	4077233
Oxidizer Bleed Valve	309029	4076750
Augmented Spark Igniter Oxidizer Valve	308880	4089946
Pressure-Activated Purge Control Valve	557823	4075865
Pressure-Activated Shutdown Valve Assembly	557817	4067200
Start Tank Fill/Refill Valve	558000	4072899
Fuel Flowmeter	251225	4076564
Oxidizer Flowmeter	251216	4077137
Fuel Injector Temperature Transducer	NA5-27441	12350
Restartable Ignition Detect Probe	NA5-27298T2	329

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter	Date Effective	Comments
Gas Generator Fuel Supply Line	RD251-4107	0.489 in.	January 4, 1968	---
Gas Generator Oxidizer Supply Line	RD251-4106	0.276 in.	January 4, 1968	---
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.430 in.	November 29, 1967	---
Oxidizer Turbine Exhaust Manifold	RD251-9004	10.00 in.	January 18, 1966	Installed on Engine before Shipment to AEDC
Main Oxidizer Valve Closing Control Line	XEOR 920651-7	8.09 scfm	January 5, 1968	---
Augmented Spark Igniter Oxidizer Supply Line	406361	0.150 in.	December 21, 1967	Sized per S-II Specifications

TABLE III

ENGINE MODIFICATIONS (BETWEEN TESTS J4-1801-22 AND J4-1801-23)

Modification Number	Completion Date	Description of Modification
RFD*-AEDC 1-68	January 5, 1968	Main Oxidizer Valve, Changes to Opening Time

*RFD - Rocketdyne Field Directive

TABLE IV

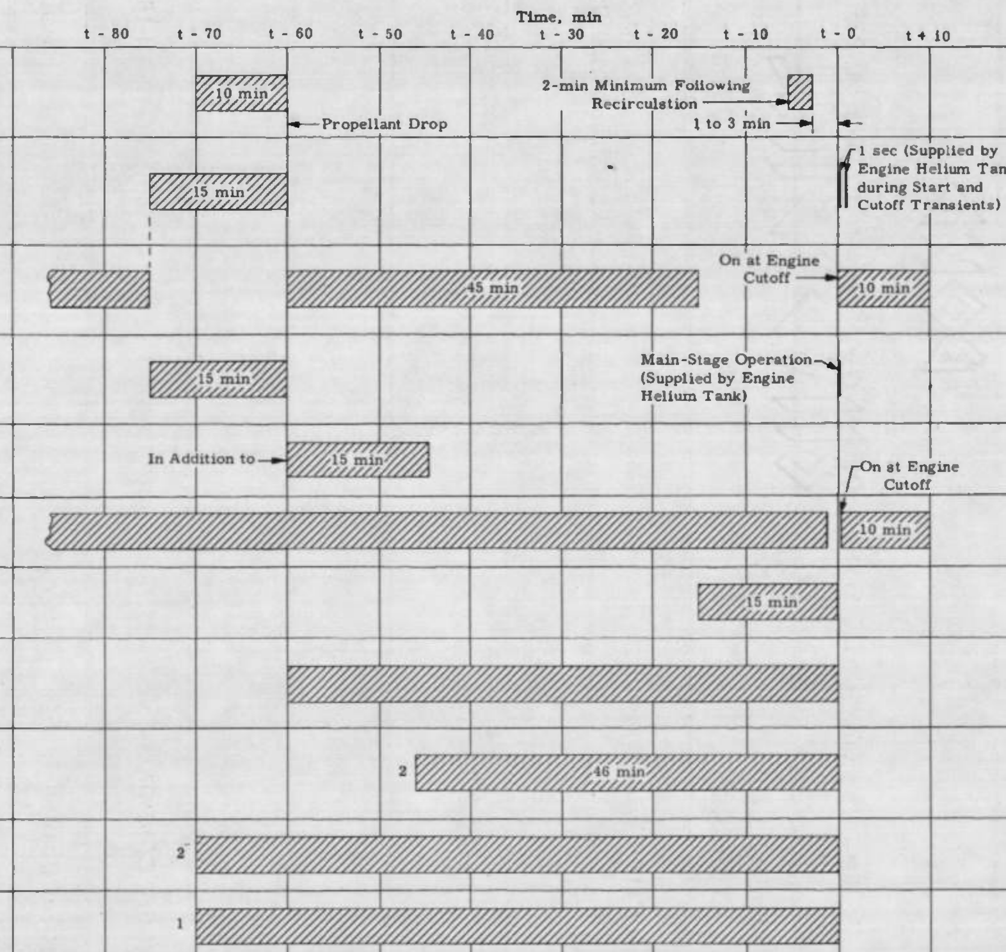
ENGINE COMPONENT REPLACEMENTS (BETWEEN TESTS J4-1801-22 AND J4-1801-23)

Replacement	Completion Date	Component Replaced
No UCR* Required Part No. NA5-27342T4 Serial No. 576	January 5, 1968	Gas Generator Overtemperature Cutoff Transducer

*UCR - Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 62 - 125 psia 50 - 200°F (Nominal) 6 scfm at Customer Connect
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Nitrogen; 400 ± 25 psig 50 - 200°F (Minimum) 230 scfm
Oxidizer Dome (Facility Line to Port CO3A)	Nitrogen; 400 - 450 psig 100 - 200°F (Nominal) 200 scfm
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 400 ± 25 psig Ambient Temperature 2600 - 7000 scfm
Thrust Chamber Jacket (Customer Connect) Panel	Helium; 40 - 60 psig 50 - 200°F (Nominal) 60 scfm
	Helium; 12 - 14 psig 50 - 200°F (Nominal) 10 scfm
Thrust Chamber Temperature Conditioning	Helium; 1000 psig -300°F to Ambient 10 - 20 lb_m/min
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia -298 to -280°F Fuel; 28 to 46 psia -424 to -416°F
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 to 1400 psia -300 to -140°F Helium; 1700 to 3250 psia -300 to -140°F
Start Tank Discharge Valve Temperature Conditioning	Helium; Ambient
Crossover Duct Temperature Conditioning	Helium; -300°F to Ambient



[1]Conditioning temperature to be maintained for the last 15 min of pre-fire.

[2]Conditioning temperature to be maintained for the last 30 min of pre-fire.

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J4-1801-		23A Target	23A Actual	23B Target	23B Actual	23C Target	23C Actual	23D Target	23D Actual	23E Target	23E Actual
Firing Date/Time of Day, hr		1-10-68	1208	1-10-68	1354	1-10-89	1504	1-10-88	1709	1-10-69	1909
Pressure Altitude at Engine Start, ft		100,000	105,500	100,000	112,500	100,000	113,000	100,000	111,500	100,000	110,500
Firing Duration, sec		30	32.573	5	7.590	5	7.588	5	7.589	+0.8*	0.950
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	25.5^{+1}_{-0}	26.3	25.5^{+1}_{-0}	25.9	25.5^{+1}_{-0}	28.4	41.0 ± 1	41.1	23.5^{+1}_{-0}	24.7
	Temperature, °F	-421.4 ± 0.4	-421.9	-421.4 ± 0.4	-422.0	-421.4 ± 0.4	-421.7	-421.4 ± 0.4	-421.3	-421.4 ± 0.4	-421.4
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	33.0^{+1}_{-0}	33.8	33.0^{+1}_{-0}	34.8	33.0^{+1}_{-0}	33.7	33.0^{+1}_{-0}	33.4	28.0 ± 1	28.2
	Temperature, °F	-294.5 ± 0.4	-294.6	-294.5 ± 0.4	-284.8	-294.5 ± 0.4	-284.8	-294.5 ± 0.4	-294.1	-295.0 ± 0.4	-295.1
Start Tank Conditions at Engine Start	Pressure, psia	1200 ± 10	1200	1200 ± 10	1197	1250 ± 10	1243	1250 ± 10	1249	1400 ± 10	1384
	Temperature, °F	-200 ± 10	-201	-200 ± 10	-201	-140 ± 10	-141	-140 ± 10	-139	-240 ± 10	-241
Helium Tank Conditions at Engine Start	Pressure, psia	---	2050	---	2157	---	2205	---	2129	---	2127
	Temperature, °F	---	-198	---	-194	---	-139	---	-139	---	-231
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat	-275 ± 25	-274	-150^{+20}_{-10}	-157	-275 ± 25	-282	-150^{+20}_{-10}	-154	-275 ± 25	-267
	Average	---	-290	---	-171	---	-309	---	-165	---	-289
Crossover Duct Temperature at Engine Start, °F	TFTD-2	-100^{+25}_{-0}	-88	-100^{+25}_{-0}	-94	-100^{+25}_{-0}	-93	-100^{+25}_{-0}	-99	+50 ± 25	+37
	TFTD-3		-81		-93		-86		-89		+44
	TFTD-9		-87		-92		-85		-91		+34
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F		---	-20	---	-17	---	-33	---	-24	---	-21
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F		-150 ± 50	-137	-150 ± 50	-110	-150 ± 50	-141	-150 ± 50	-141	---	-130
Fuel Lead Time, sec		1.0	1.000	1.0	1.000	1.0	1.002	1.0	1.003	1.0	0.999
Propellant in Engine Time, min		Minimum 30	99	Minimum 30	49	Minimum 30	69	Minimum 30	124	30	30
Propellant Recirculation Time, min		10	10	10	10	10	10	10	11	10	10
Prevalve Sequencing Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Start Tank Discharge Valve Opening Temperature at Engine Start, °F		+50 ± 25	+27	+50 ± 25	+31	+50 ± 25	+28	+50 ± 25	+26	+50 ± 25	+34
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t_0		--- / ---	28 / 1.047	--- / ---	8 / 1.032	--- / ---	47 / 1.055	--- / ---	24 / 1.035	--- / ---	--- / ---
Gas Generator Outlet Temperature, °F	Initial Peak	---	1814	---	1407	---	1412	---	1182	---	1688 after Shutdown
	Overshoot	---	---	---	---	---	---	---	1217	---	---
Main Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0)		---	1.050	---	1.035	---	1.070	---	1.035	---	N/A
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)		---	1.017	---	1.044	---	1.080	---	1.044	---	N/A
Main-Stage Pressure No. 2, sec (Ref. t_0)		---	1.843	---	1.753	---	1.832	---	1.737	---	N/A
550-psia Chamber Pressure Attained, sec (Ref. t_0)		---	2.150	---	2.075	---	2.150	---	2,025	---	N/A
Propellant Utilization Valve Position at Engine Start, Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---

N/A = Not Applicable

*Main-Stage Solenoid On

TABLE VII
ENGINE VALVE TIMINGS

Firing Number J4-1801-	Start																								
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
23A	0	0.142	0.123	0.447	0.081	0.243	-1.000	0.054	0.058	0.447	0.082	0.047	0.447	0.570	1.852	0.447	0.113	0.030	0.447	0.182	0.073	0.447	0.239	0.270
23B	0	0.140	0.125	0.448	0.085	0.250	-1.000	0.055	0.060	0.448	0.058	0.054	0.448	0.586	1.853	0.448	0.115	0.033	0.448	0.185	0.080	0.448	0.240	0.270
23C	0	0.140	0.124	0.444	0.081	0.241	-1.002	0.057	0.070	0.444	0.060	0.057	0.444	0.818	1.806	0.444	0.118	0.033	0.444	0.194	0.078	0.444	0.242	0.272
23D	0	0.140	0.125	0.444	0.080	0.245	-1.003	0.048	0.080	0.444	0.055	0.060	0.444	0.600	1.940	0.444	0.118	0.030	0.444	0.195	0.080	0.444	0.240	0.285
23E	0	0.143	0.132	0.443	0.080	0.240	-0.888	0.053	0.065	0.443	0.055	0.057	0.443	N/A	N/A	0.443	0.120	0.030	0.443	0.200	0.078	0.443	0.240	0.270
Pre-Fire Final Sequence	0	0.100	0.115	0.445	0.085	0.250	-1.002	0.045	0.071	0.445	0.052	0.052	0.445	0.580	1.770	0.445	0.091	0.035	0.445	0.150	0.068	0.445	0.230	0.283

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
23A	32.573	0.132	0.350	32.573	0.088	0.189	32.573	0.050	0.080	32.573	0.018	0.018	32.573	0.211	0.438
23B	7.590	0.130	0.334	7.590	0.080	0.177	7.590	0.061	0.021	7.580	0.030	0.018	7.580	0.220	0.450
23C	7.588	0.144	0.372	7.588	0.080	0.184	7.588	0.062	0.020	7.588	0.030	0.016	7.588	0.220	0.453
23D	7.588	0.144	0.382	7.588	0.080	0.187	7.588	0.062	0.023	7.588	0.029	0.018	7.588	0.221	0.454
23E	0.850	0.113	0.310	0.850	N/A	N/A	0.850	0.072	0.035	0.850	0.045	0.018	0.950	0.080	0.485
Pre-Fire Final Sequence	7.745	0.086	0.240	7.745	0.067	0.133	7.745	0.078	0.108	7.745	0.052	0.021	7.745	0.200	0.441

Notes:
1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or valve "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data reduced from oscillogram.
5. N/A = Not Applicable

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1801-		23A	
		Site	Normalized
Overall Engine Performance	Thrust, lbf	237,910	236,280
	Chamber Pressure, psia	795.9	787.2
	Mixture Ratio	5.428	5.438
	Fuel Weight Flow, lb_m/sec	85.39	84.37
	Oxidizer Weight Flow, lb_m/sec	463.49	458.83
	Total Weight Flow, lb_m/sec	548.88	543.20
Thrust Chamber Performance	Mixture Ratio	5.629	5.642
	Total Weight Flow, lb_m/sec	541.76	536.13
	Characteristic Velocity, ft/sec	8042	8037
Fuel Turbopump Performance	Pump Efficiency, percent	73.9	73.9
	Pump Speed, rpm	27,432	27,298
	Turbine Efficiency, percent	63.0	62.9
	Turbine Pressure Ratio	7.21	7.20
	Turbine Inlet Temperature, °F	1206	1192
	Turbine Weight Flow, lb_m/sec	7.12	7.07
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.4	80.4
	Pump Speed, rpm	8681	8622
	Turbine Efficiency, percent	48.8	48.6
	Turbine Pressure Ratio	2.68	2.68
	Turbine Inlet Temperature, °F	775	766
	Turbine Weight Flow, lb_m/sec	6.31	6.26
Gas Generator Performance	Mixture Ratio	0.943	0.935
	Chamber Pressure, psia	689.5	683.6

Notes:
1. Site data are calculated from test data.
2. Normalized data are corrected to standard pump inlet and engine ambient pressure conditions.
3. Input data are test data averaged from 29 to 30 sec.
4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC Test J4-1801-23 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFJT	Fuel Injector Temperature		On/Off	x		x		
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x		x		
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2		On/Off			x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QF-2SD	Fuel Flow Stall Approach Monitor		0 to 9000	x		x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x			x	
	Heat Flux		watts/Sr. cm^2					
RTCEP	Radiation Thrust Chamber Exhaust Plume		0 to 7	x				
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCGG-1P	Gas Generator Chamber Pressure		0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASIJ	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFMI	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x				x
PFPI-2	Fuel Pump Inlet		0 to 200	x				x
PFPI-3	Fuel Pump Inlet		0 to 200		x	x		
PFPPSD-1	Fuel Pump Primary Seal Drain		0 to 200	x				
PFPS-1P	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFTSP-1	Fuel Turbine Seal Purge Line		0 to 100	x				
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PGGOC	Gas Generator Opening Control		0 to 500	x				
PGGVB	Gas Generator Valve Body		0 to 50	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHES	Helium Supply		0 to 5000	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure		psia					
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x		x		
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1D	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO5	0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x			
POVI	Oxidizer Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0 to 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTCP	Thrust Chamber Purge		0 to 15	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	Temperatures		°F					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBPM	Bypass Manifold		-325 to +200	x				
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	

TABLE III-1 (Continued)

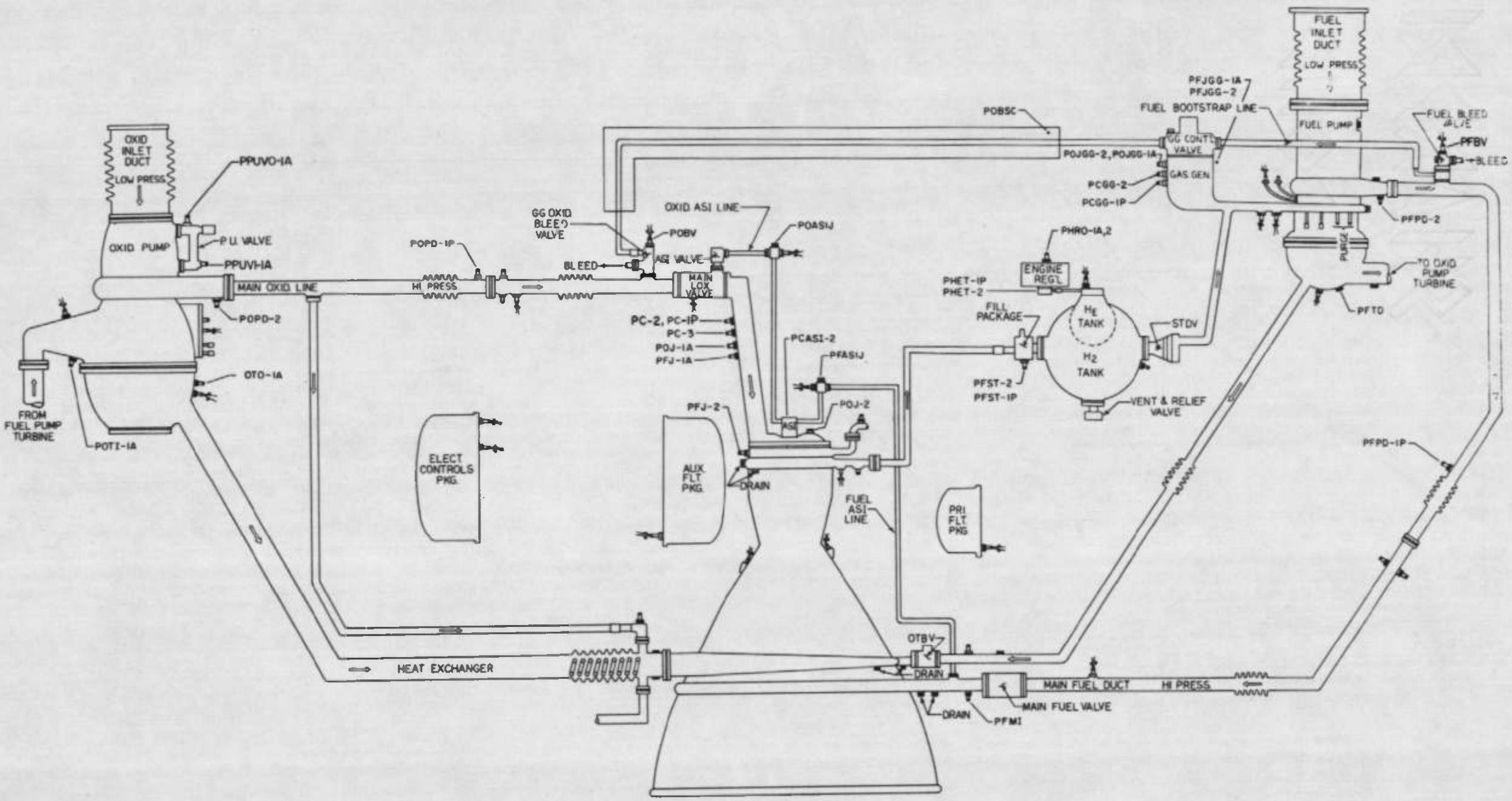
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to -100	x		x		
TFASIL-1	Augmented Spark Igniter Line		-300 to -250	x				
TFASIL-2	Augmented Spark Igniter Line		-300 to -350	x				
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFD-1	Fire Detection		0 to 1000	x			x	
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-3	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to -100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to -1000	x			x	
TFTD-3R	Fuel Turbine Discharge Line		-200 to -800	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTI-1P	Fuel Turbine Inlet	TFT1	0 to 1800	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TFTSD-1	Fuel Turbine Seal Drain Line		-300 to +100	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x		x		
TGGVRS	Gas Generator Valve Retaining Screw		-100 to +100	x				
THET-1P	Helium Tank	NNT1	-350 to +100	x				x
TNODP	Liquid Oxygen Dome Purge		0 to -300	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to -250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to -250	x				
TOBS-2A	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3	Oxidizer Bootstrap Line		-300 to -250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to -250	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-1B	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Pressurization Line Nozzle Throat		-300 to +100	x				
TPCC	Pre-Chill Controller		-425 to -300	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to +500	x				
TSC2-7	Thrust Chamber Skin		-300 to +500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500	x				
TSC2-9	Thrust Chamber Skin		-300 to +500	x				
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to +500	x				
TSC2-15	Thrust Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x			x	
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to -100	x			x	

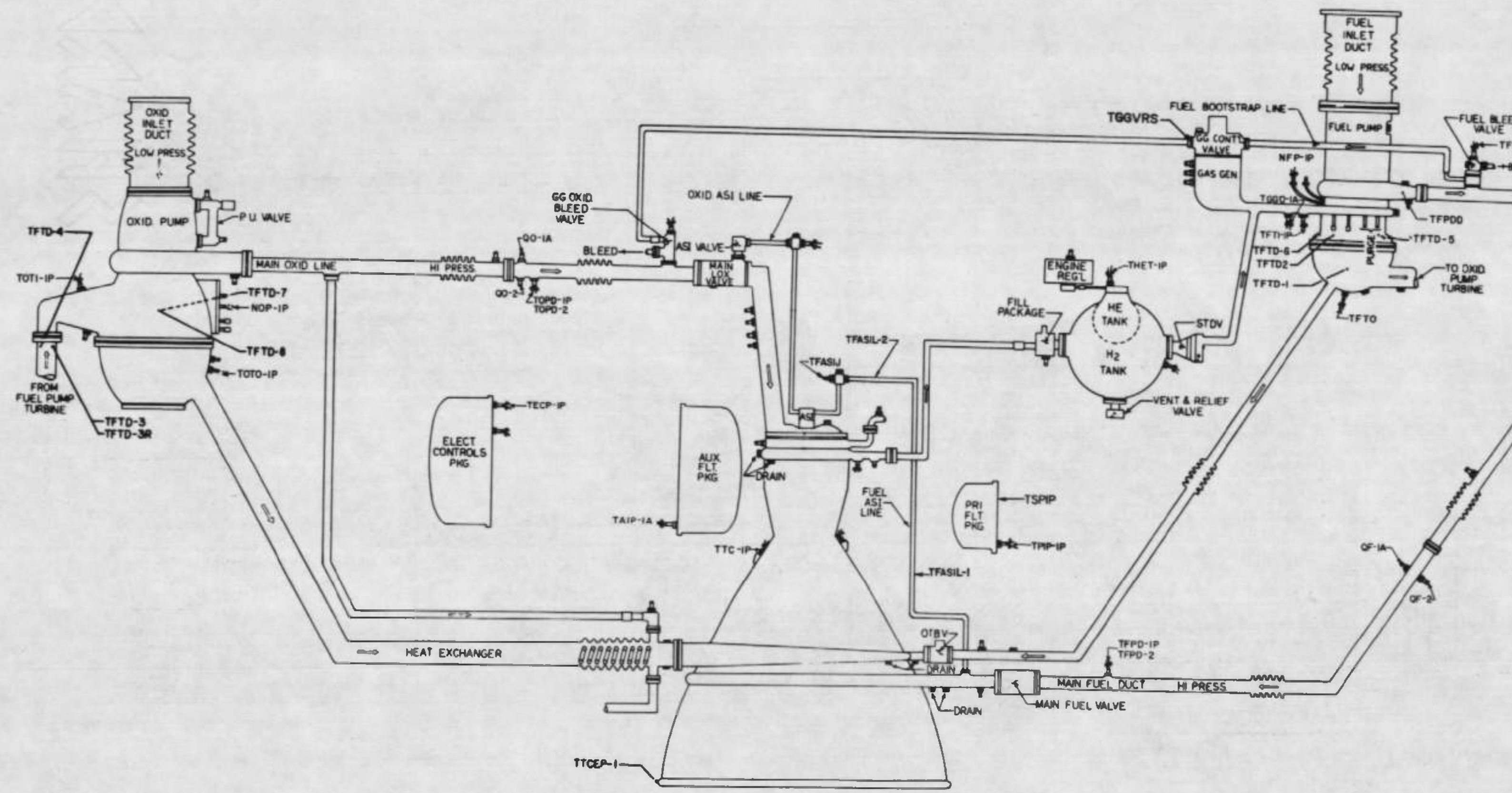
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x			x	
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TTPP	Turbopump Purge		-150 to +150	x				
TXOC	Crossover Duct Conditioning		-325 to -200	x				
	Vibrations		g's					
UFPR	Fuel Pump Radial 90 deg		±200		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		Volts					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				

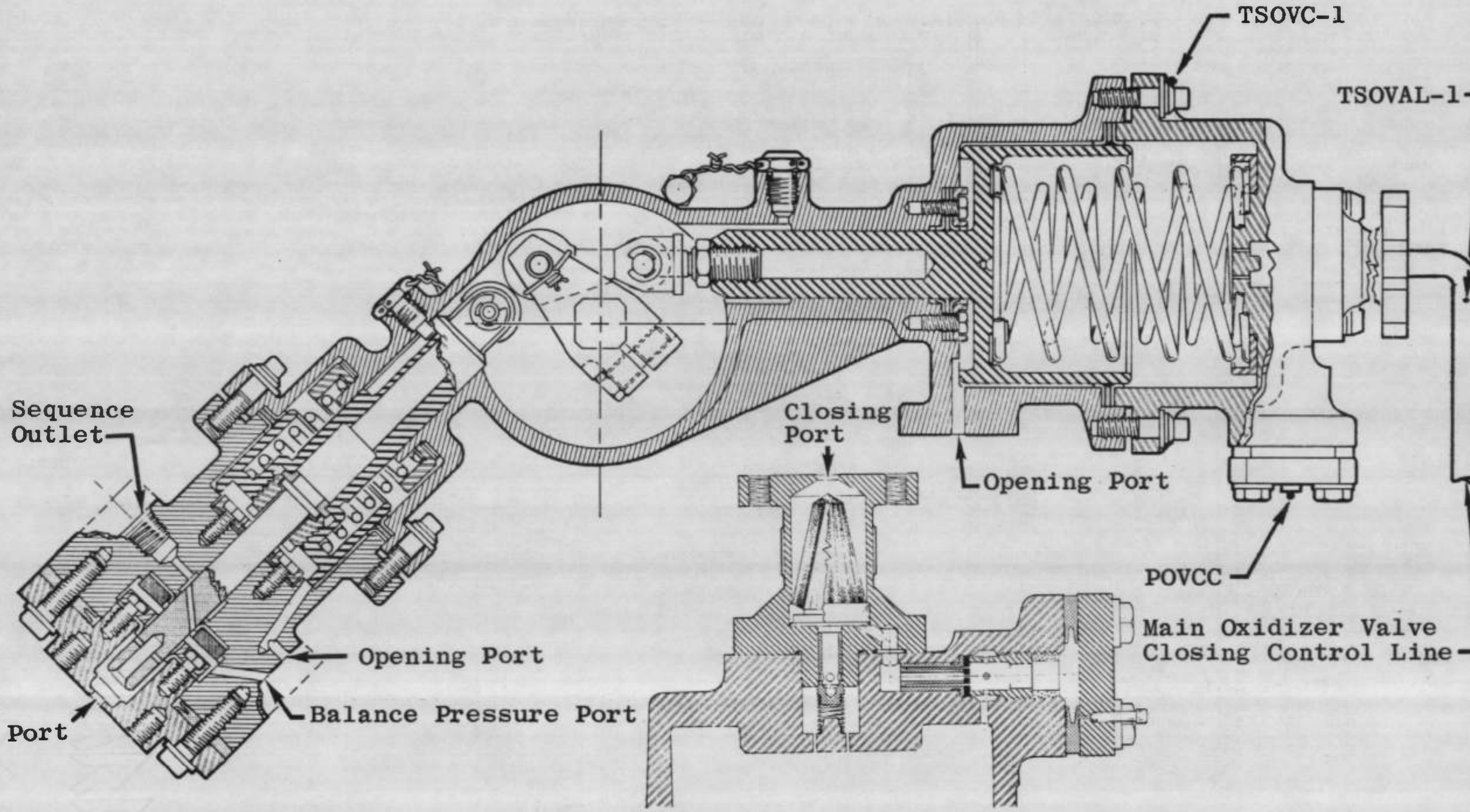


a. Engine Pressure Tap Locations

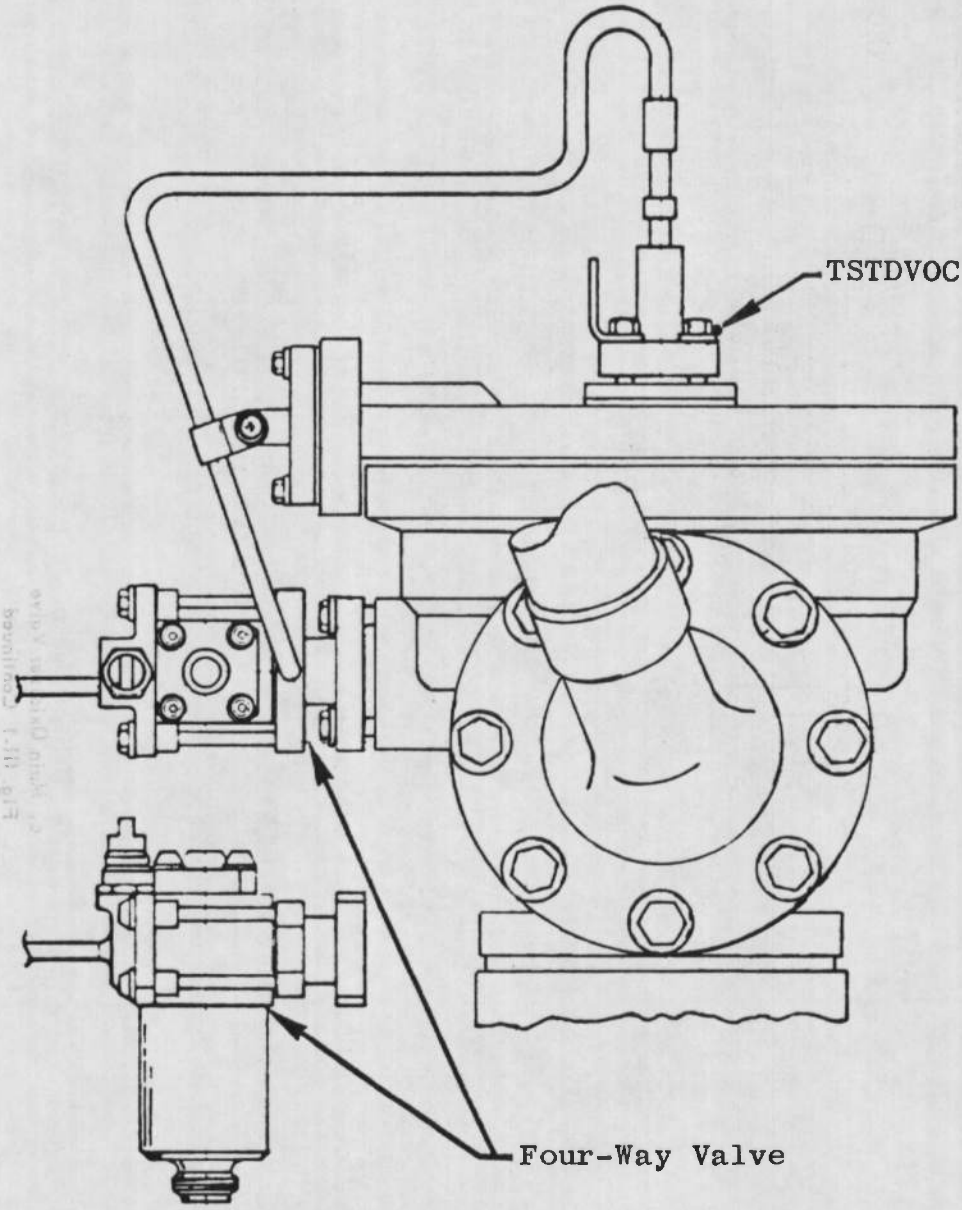
Fig. III-1 Instrumentation Locations



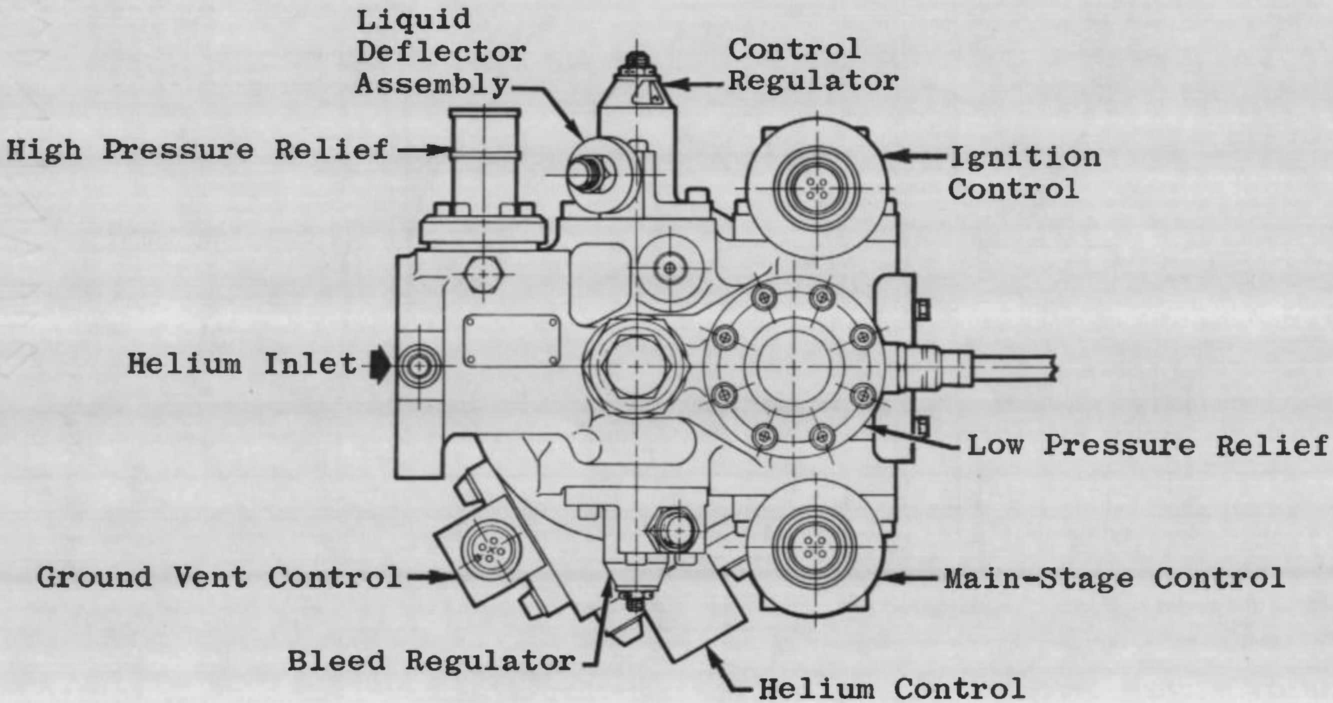
b. Engine Temperature, Flow, and Speed Instrumentatian Locations
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued



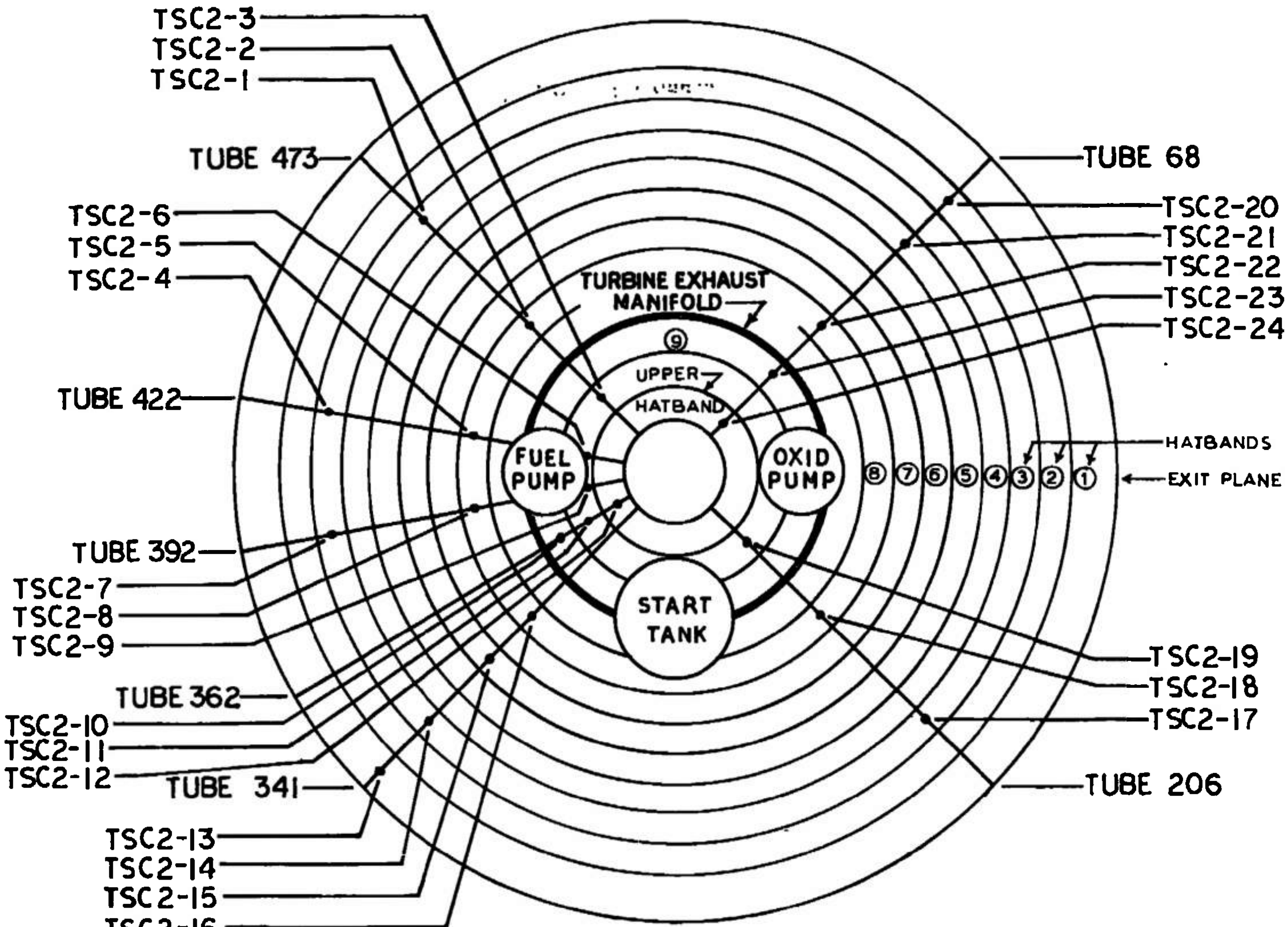
d. Start Tank Discharge Valve
Fig. III-1 Continued



Top View

e. Helium Regulator

Fig. III-1 Continued



VIEW LOOKING AFT

f. Thrust Chamber
Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, volts
10	Propellant Utilization Valve Position, volts
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FIT	Fuel turbine inlet
FM	Fuel measured
FY	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
T_o	Turbine oxidizer
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

$$W_E = W_{EO} + W_{EF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = 0.9 \text{ lb/sec}$$

$$W_{XF} = 2.1 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{G_F} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF}\, A_{TIF}\, K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

$$W_C = W_{CO} + W_{CF}$$

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7\, P_c\, A_t}{W_C}$$

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$

$$P_{IF} = 30 \text{ psia}$$

$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$

$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$

$$T_{IO} = -295.212\,°F$$

$$T_{IF} = -422.547\,°F$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$

$$K_4 = 144$$

$$\rho = \text{National Bureau of Standards Values f (P,T)}$$

Fuel

$$H_f = 778.16\,\Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P,T)$$

$$h_{IF} = f(P,T)$$

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\, Y_O$$

$$\eta_{OC} = K_{4O} \left(\frac{Q_{PO}}{N_O}\right)^2 + K_{5O} \left(\frac{Q_{PO}}{N_O}\right) + K_{6O}$$

$$K_{4O} = 5.0526$$

$$K_{5O} = 3.8611$$

$$K_{6O} = 0.0733$$

$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO}\ \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B\ (P_{OO})$$

$$A = -1597$$

$$B = 2.3818$$

$$\text{IF } P_{OO} \geq 1010 \text{ Set } P_{OO} = 1010$$

$$\ell n\, R_v = A_3 + B_3\,(\theta_{PUVO}) + C\,(\theta_{PUVO})^3 + D_3\,(e)^{\frac{\theta_{PUVO}}{7}} + E_3\,(\theta_{PUVO})\,(e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}}\right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

$$\theta_{PUVO} = 16.5239$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10}\ \Delta h_f\ W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF}\ H_f}{\eta_f}\right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} \ H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7 \ \gamma_{H2}}{\gamma_{H2-1}} (P_{RNC})^{\frac{2}{\gamma_{H2}}}\right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2-1}}{\gamma_{H2}}}\right] \frac{A_{NB} \ P_{BNI}}{(R_{H2} T_{BIR})^{1/2}}$$

$$P_{RNC} = f\ (\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, r_G)$$

$$A_{NB} = K_{13}\ D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} - 460$$

$$P_{BNI} = P_{TEFS}$$

P_{TEFS} = Iteration of P_{TEF}

$$P_{TEF} = P_{TEFS} \left[1 + K_8 \left(\frac{W_T}{P_{TEFS}}\right)^2 \frac{T_{H2R}}{D^4_{TEF}\ M_{H2}} \left(\frac{\gamma_{H2-1}}{\gamma_{H2}}\right)\right]^{\frac{\gamma_{H2}}{\gamma_{H2-1}}}$$

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS} \left[1 + K_8 \left(\frac{W_T}{P_{TIFS}} \right)^2 \frac{T_{H1R}}{D^4_{TIF} M_{H1}} \quad \frac{\gamma_{H1} - 1}{\gamma_{H1}} \right]^{\frac{\gamma_{H1}}{\gamma_{H1} - 1}}$$

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{HIR} = T_{TIF}$$

$$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\,(T_{HIR}, r_G)$$

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13. ABSTRACT

Five firings of the Rocketdyne J-2 rocket engine (S/N J-2047) were conducted in Test Cell J-4 of the Large Rocket Facility on January 10, 1968. The firings were accomplished during test period J4-1801-23 at pressure altitudes ranging from 105,500 to 113,000 ft at engine start to evaluate the effects of predicted Saturn S-II stage pre-fire conditions on J-2 engine start transients. Engine components were thermally conditioned to simulate the expected S-II interstage/engine thermal environment. Satisfactory engine operation was obtained. Accumulated firing duration was 56.3 sec.

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